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Wartime Medical Requirements Models: A Comparison of MPM, MEPES, and LPX-MED

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The end of the Cold War has led to a major reexamination of the requirements for medical personnel and other resources necessary to care for Department of Defense (DoD) beneficiaries. Despite large numbers of peacetime beneficiaries, the primary need for medical resources remains the wartime mission. During the Cold War, the requirement for wartime medical providers was high and could easily justify large numbers of active duty personnel. Today's defense guidance is based on fighting two major regional contingencies (MRCs), and the required number of medical providers has fallen sharply. Determining the number and types of medical resources needed to treat casualties of future conflicts is an important and complicated issue. To help shed light on the process of determining wartime medical requirements, N-931 asked CNA to examine the methods and models that are currently in use or may be used in the near future. The current process is in flux. The models used today are being changed. The use of one model was discontinued recently when the Joint Staff changed to a new command-and-control system. The Joint Staff has proposed a replacement, but the new model is still being developed and there is some concern about its adequacy in determining service medical requirements. In this memorandum, we examine the current and proposed theater-level requirements models.

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Introduction and summary

The end of the Cold War has led to a major reexamination of the requirements for medical personnel and other resources necessary to care for Department of Defense (DOD) beneficiaries. Despite large numbers of peacetime beneficiaries, the primary need for medical resources remains the wartime mission. During the Cold War, the requirement for wartime medical providers was high and could easily justify large numbers of active duty personnel. Today's defense guidance is based on fighting two major regional contingencies (MRCs), and the required number of medical providers has fallen sharply.

Determining the number and types of medical resources needed to treat casualties of future conflicts is an important and complicated issue. To help shed light on the process of determining wartime medical requirements, N-931[1] asked CNA to examine the methods and models that are currently in use or may be used in the near future.

The current process is in flux. The models used today are being changed. The use of one model was discontinued recently when the Joint Staff changed to a new command-and-control system. The Joint Staff has proposed a replacement, but the new model is still being developed and there is some concern about its adequacy in determining service medical requirements.

In this memorandum, we examine the current and proposed theater-level requirements models. We have three main objectives:

- Understand the methods that generate requirements.
- Identify each model's relative strengths and weaknesses.
- Recommend improvements to the models.

1. N-931 is the Medical Resource, Plans, and Policy Division within the Office of the Chief of Naval Operations (N-093).

Approach

We began by examining the process that determines the wartime requirements. Mathematical models are an important part of the process. These models represent in simple, yet we hope realistic, terms a consistent way of predicting medical requirements in support of OPLAN development. The models rely on a series of inputs, assumptions, and DOD policies that are represented by a series of mathematical relationships. The mathematical equations are used in two ways: (1) to generate a stream of casualties who require medical attention and (2) to determine an appropriate level of resources required to treat the casualties in the combat zone or, after evacuation, at medical care sites away from the battlefield.[2]

In this memorandum, we describe three mathematical models that the Joint Staff and the individual services use to derive theater-level medical resources. Other models are used in the process, generally by the individual services to determine requirements for their specific medical platforms (e.g., for the Navy, its fleet hospitals). Here, we've focused on the following theater-level models:

- Medical Planning Module (MPM)
- Medical Planning and Execution System (MEPES)
- External Logistics Processor-Medical Module (LPX-MED).

Much of the analysis concentrated on examining the various inputs and assumptions that are an integral part of the models. These inputs, or planning factors, include casualty rates and lengths of stay. Some of the inputs also represent evacuation policies and treatment protocols or procedures.

2. The levels of care are called echelons. Little care is provided at the first echelon, which is close to the combat unit itself. Second-echelon facilities include medical battalions and combat casualty receiving ships that have some medical capability. Third-echelon facilities include the Navy's hospital ships (T-AHs) and fleet hospitals. Fourth-echelon, or communication zone, facilities include host nation hospitals and those outside the continental United States (OCONUS). Fifth echelon refers to hospitals in CONUS.

After describing these factors and the underlying method each model uses to determine a requirement, we compared the results from the models using a common scenario. These models focus on theater-level requirements, so we concentrate our discussion on bed requirements because that requirement directly affects the requirement for other resources, such as personnel and supplies.

Note that the new model—still under development—will consist of two of the models that we examine here. Although there was some discussion of using LPX-MED to generate wartime medical requirements, the current plan is to incorporate much of MPM, the current requirements generator, into LPX-MED.[3]

Findings

Based on our analysis, our major findings include:

- MEPES, which was the original planned successor to MPM, was designed to allow many more operational zones. This is an improvement. The other major difference is how it handles those who return to duty, which in most cases, reduces the bed requirement when compared to MPM.
- LPX-MED is a simulation model. Although the model itself will not be used to generate requirements directly, the data it relies on will be used. Using the model to generate requirements helped us understand how its underlying assumptions and treatment data affect the ultimate requirements calculations, even if a calculator-type model, such as MPM, is used.
- LPX-MED produces lower bed requirements than the current MPM, primarily for the following reasons:

3. This raises questions concerning just which changes were made to MPM's underlying mathematical formulation and how the new version compares to the version that was part of the Joint Operation Planning and Execution System (JOPES). See appendix A for a discussion of these and other issues.

- Differences in treatment protocols that, in LPX-MED, send almost everyone back to CONUS for at least some portion of their care. MPM, on the other hand, will treat and return to duty many more casualties, especially disease and non-battle injury (DNBI) casualties, in theater.
- Differences in the way the two models round the time spent in functions during the day. In MPM, patients spend whole days in such functions; in LPX-MED, they spend as little as a tenth of an hour.
- The use in MPM of the dispersion allowance, which is a multiplicative factor that represents uncertainty or the "fog of war." LPX-MED includes no such factor.

- But, if the same underlying treatment data and other planning factors from LPX-MED are used in MPM, it too will generate much lower theater-level bed requirements.

Recommendations

To improve the models and the process of determining requirements, we recommend the following:

- Although the current plan is to modify LPX-MED to include a requirements calculator, there is no plan to link the requirements calculation module and the simulation module. We believe the simulation module (i.e., today's LPX-MED) needs reasonable starting values, which a calculator model can provide. However, MPM or MEPES must be modified to be integrated into LPX-MED. For example,
  - To be truly complementary models, both the calculator and simulation must use and apply the same treatment data in a consistent manner.
  - Variables must also match. For example, MPM calculates two bed types, MEPES calculates four, and LPX-MED simulates six. The calculator model should be expanded to allow six bed types.

— If the simulation indicates shortfalls, it must be linked back to the calculator model for the latter to "efficiently" recalculate a new set of requirements.

- The current models are poorly documented. Any new model should include two types of information. First, there should be documentation on the conceptual relationships, equations, etc., that the model uses to derive requirements. Second, the output of any run should clearly describe all input values and planning factors used in the run.
- Major planning factors, such as the underlying treatment data and evacuation assumptions, should be examined and validated. The assumptions and data must reflect realistic wartime medical treatment today and in the future.

Requirements process

Background

In this report, we focus on today's macro-level medical requirements models. Although in the past these models were provided to the medical planner as just other planning tools, they have recently become much more—an integral part of the programming and budgeting process that forms the basis of the medical force structure. Area commanders-in-chief (CINCs) also use the same theater-level models, perhaps with some modification, for medical planning during contingencies. Despite the added importance of the models' output, in many cases, there has been no careful examination of the models to determine if they can really do the job. Much of our analysis is designed to help shed light on what these tools can and cannot do.

At present, the MPM is the only DOD-approved model. The MPM, however, can no longer be used to generate requirements because the old version cannot be directly integrated into the Joint Staff's new Global Command and Control System (GCCS) that is now being fielded. LPX-MED had been envisioned as a successor to MPM, not only to determine whether a planned set of medical resources would be adequate, but as a requirements generator as well. However, the latest plan from the Joint Staff is to create an MPM-like "front-end" to LPX-MED. The new model, which is still under development, will consist of the two somewhat independent tools—MPM and LPX-MED—and will be called the Medical Analysis Tool (MAT).

Whichever model the Joint Staff uses, its derived requirements depend on the model's assumptions and how these assumptions have been translated into mathematical relationships and variable values. In many cases, the relative importance of key planning factors in the requirements process are not well understood by the medical planners who need to rely on them. Small changes in an assumed input

value, one that is not well documented by the model output, can lead to relatively large changes in the final set of bed requirements.

Thus, to understand the process and how theater-level bed requirements are derived, it's important to understand some general characteristics of the models and of the planning factors the models require. Later in the paper, we'll provide more details concerning how each model calculates requirements or, in the case of LPX-MED, evaluates the assumed levels of resources placed in its network. In this section, we provide an overview of the following important parts of the requirements process:

- The type of model used
- The assumptions and critical planning factors required by each model
- The relationship of the models and inputs to DOD policies regarding evacuation, treatment in theater, and so on.

Calculator versus simulation models

Theater-level models differ in design and purpose. Possibly the most important difference concerns whether they *calculate* a requirement or *simulate* what is likely to happen given some set of requirements.

Two of the models we've been examining—MPM and MEPES—fit the category of calculator models. These models calculate a bed requirement at the third, fourth, and fifth echelons from a given set of mathematical relationships. For example, for a given population at risk and a given wounded-in-action (WIA) rate, simple multiplication leads to that day's expected number of wounded. With a few more assumptions about how many of the wounded might die or how long before they get evacuated, a relatively simple calculation leads to the number of beds required for their daily care at that echelon. Without oversimplifying the process, the main point is that what comes out of the model is a bed requirement. The calculation may be crude, the assumptions may be too simple, and the resulting requirement may not be specific enough (e.g., an overly broad definition of bed type).

Nonetheless, the model calculates how many beds would be required on each day of the conflict.

LPX-MED is a good example of the second kind of model. As originally designed, there is no calculation of how many beds would be required for an assumed scenario. Instead, the user must first design a network of medical facilities and populate each "node" of the network with medical resources, such as beds or medical personnel. Then, given certain variables whose values depend on an assumed probabilistic outcome, the model evaluates how well the resources present in the network perform in treating and/or evacuating casualties. This type of model is also referred to as a "course of action" analyzer. The tool, as initially designed, evaluates a given set of resources; it does not calculate them.

The two types of tools—a calculator and course-of-action analyzer—would seem to be complementary in nature, not substitutes for each other. The Joint Staff, however, recently attempted to use LPX-MED to generate a set of requirements by assuming a simple network composed of one huge facility at each echelon with more than enough medical resources and evacuation assets at its disposal. A scenario would be assumed and the model run with this "megafacility" and ample medical and evacuation assets. A "requirement" for beds and other resources would then be generated from the resources actually used over the course of the simulation. One problem with this type of model is that there would never be any bottlenecks or shortages; therefore, it represents the outcome of a "perfect world."

Might this procedure work as a requirements generator? Perhaps, but the true test of any requirements calculator is what happens when these resources are simulated under more realistic conditions. If serious bottlenecks and shortages result, it isn't clear what to do next. Assume a slightly higher level and replay the simulation? This kind of procedure is time-consuming to run and may never lead to an adequately resourced network. A better procedure seems to be to use a true requirements calculator, which can be modified or generalized over time, in conjunction with the LPX-MED simulation or course-of-action analyzer. Indeed, the present plan is to use an MPM-like calculator model as a first phase in MAT. For that reason, it's important to

evaluate the three models to determine how well each might do in this more complete requirements model.

Critical planning factors and policies

We've already stated that both calculator and simulation models represent important factors by various input variables. A key question in any analysis of the models is how well they and their planning factors represent the "real world."

All of the models we'll study have at least four general categories of critical factors, which we've listed below:

- Population at risk (PAR)
- Casualty rates
- Lengths of stay
- Evacuation policy.

The PAR and casualty rates

The PAR represents the population of each service assumed to be at risk of being wounded in battle, coming down with disease, or facing a nonbattle injury (NBI). None of the models actually develop their own PAR; they all rely on the Time-Phased Force and Deployment Data (TPFDD). The computer programs within each model are designed to read the TPFDD and calculate the PAR daily.

The second planning factor may be the most controversial—the casualty rates used by each model. Much of the controversy associated with casualty rates has nothing to do with the medical models—it simply reflects the concern that warfare is complex, uncertain, and can never be predicted well.

All three models—MPM, MEPES, and LPX-MED—use much the same methodology to estimate the number of casualties. They calculate the number of casualties on any given day by multiplying that period's PAR by the day's casualty rate. All three models allow casualty rates to vary by combat intensity, type of casualty (WIA versus disease

or NBI, the latter often referred to as DNBI), and type of unit (combat versus support). Given the same scenario and assuming full troop replacement, the models produce virtually the same casualty stream; the only differences would be due to rounding.

The models differ, however, in their degree of aggregation. MPM is an aggregate model that treats the battlefield as a single sector with one level of combat intensity on any day. There are three operational zones (OPZONEs), representing combat, communications, and CONUS. It does allow the combat and communications zones to be subdivided into the combat and combat support elements, with the typical assumption that the support unit faces a lower combat intensity level. All of the PAR within that sector faces the same combat intensity. It can change over time, but not by unit.

Both MEPES and LPX-MED allow for *sectoring*. MEPES allows up to 5 OPZONEs and up to 6 sectors within each OPZONE, for a grand total of at most 30 sectors. LPX-MED allows combat intensities to vary across units during a given time period. In theory, it allows for as many sectors within echelons 2 through 4 as the user decides to input. In practice, however, LPX-MED is constrained by the level of complexity the user is willing to input. The more complex the scenario, the greater the input data requirements and the longer the model will need to run.

The advantage of sectoring the battlefield is that, conceptually, it allows for a much more detailed application of casualty rates expected for specific units, rather than a general rate applied to everyone. Because LPX-MED and, to some extent, MEPES can handle varying size units and combat intensities, they are more flexible and can better accommodate new battlefield tactics in which troops may deploy in small, dispersed teams. Even LPX-MED, however, is not well suited to handle rapid troop movements or rapidly changing medical network configurations.

Lengths of stay and evacuation policies

The third and fourth planning factors pertain to the expected casualty treatment times and the evacuation policies for those who require additional care at a higher echelon facility. The lengths of stay and

evacuation policies are key factors required in any evaluation of medical resources needed during wartime.

The evacuation policy drives who is treated in theater, which has important implications for the theater-level requirement. The longer the evacuation policy, the longer casualties spend in theater receiving care. More time in theater leads to greater numbers returning to duty and fewer replacements for casualties. It would also tend to maximize the theater-level infrastructure and medical resources, such as beds.

The following factors represent the effects of the evacuation policy:

- The percentage of casualties who would require an average length of stay (ALOS) greater than the stated policy
- The time spent in a facility for evacuees and for those who return to duty at the echelon
- The evacuation delay time, which is a function of patient stabilization time, administration time, and time awaiting lift.

Even though the policy regarding theater-level treatment or evacuation may be the same, the models differ in the way they translate the policy and use it in their requirement calculations. First, we'll describe some of the differences in the planning factors themselves. In a later section, we'll focus more on the how models use these factors to determine requirements.

Comparing treatment and evacuation factors in MPM and MEPES

MPM and MEPES are similar models and rely on many of the same planning factors, but with one important difference. MPM's calculated bed requirements depend on the value of the ALOS for those who it assumes will eventually return to duty, but MEPES' requirement calculations do not.

Before we explain this difference, let's start with some of the similarities. Both rely heavily on the simple representation of evacuation policy, as shown in table 1.

Table 1. Evacuation policy

OPZONE	Theater/CONUS	Evac policy/evac delay (days)
1	T	7/3
2	T	15/5
3	C	60/10

The table shows three OPZONEs[4]—two in theater and one in CONUS—and the OPZONE's combination of evacuation policy and the evacuation delay, both stated in terms of days. The table can be used in either model, although MPM considers only three OPZONEs; MEPES can allow many more.

Further, the table illustrates the evacuation policy used today for programming future resources. Evacuation policy at OPZ 1 is 7 days, with an assumed 3-day delay. Patients with medical conditions requiring more than a 7-day ALOS would be evacuated to OPZ 2 after a 3-day delay. At OPZ 2, the policy is 15 days, but that would include the time that was spent in a bed at OPZ 1. The OPZ 3 (i.e., CONUS) policy is a bit different because the delay time in CONUS can really be thought of as a "retention" policy or schedule within the DOD health care system. A 60/10 policy would direct those casualties who require such extended lengths of stay to remain for 10 days before moving to the civilian sector for their remaining care.

In addition, MPM ties the assumed theater-level evacuation policy to evacuation rates and the ALOS. Table 2 presents evacuation rates and the assumed ALOS for different evacuation policies.

We've shaded two lines of the table to highlight the current 7- and 15-day evacuation policies. The table illustrates the close connection between the policy and the number of evacuees. For example, under a 7-day evacuation policy, 92 percent of those wounded in action will require an LOS greater than 7 days. The model will, therefore, assume that 92 percent of all WIAs will be evacuated after the

4. We'll shorten the abbreviation for operational zones even more when referring to a specific OPZONE, such as OPZ 1 or OPZ 2.

assumed delay period. The remaining 8 percent of the WIAs will return to duty after a hospital stay of 5 days. For those casualties with disease or NBI, only 67 percent will be evacuated and 33 percent can be returned to duty in 5 days.[5]

Table 2. Relationship in MPM between evacuation policy, percentage of evacuees, and ALOS

	Wounded in action		Disease		Non-battle injury	
Evacuation policy (days)	Percentage of patients evacuated	ALOS of non-evacuees	Percentage of patients evacuated	ALOS of non-evacuees	Percentage of patients evacuated	ALOS of non-evacuees
5 day	95	4	79	4	79	4
7 day	92	5	67	5	67	5
14 day	89	6	52	6	52	6
15 day	83	8	38	8	38	8
30 day	68	15	20	11	20	11

The table also illustrates one of the characteristics of MPM that we found often made it difficult to duplicate its results. According to the table, the ALOS for those who return to duty is 5 days under a 7-day evacuation policy and the ALOS is 8 days under the 15-day evacuation policy. Later in the paper, we'll present a scenario that relies on many of the values in table 2, including the same 7 and 15 day policies for OPZs 1 and 2, respectively. The scenario assumes the same evacuation rates shown in table 2 and the same ALOS at OPZ 1 (i.e., 5 days). What was difficult to find was what it really used for the ALOS at OPZ 2. It clearly didn't use 8 days.

It turned out that the scenario did not use the ALOS in the table, but rather a user-supplied value. Although allowing user-supplied values in the model offers flexibility and perhaps makes it more realistic (at

5. In MPM, the theater evacuation rate pertains to admissions at both OPZs 1 and 2. In other words, 83 percent of the WIA admissions at OPZs 1 and 2 will be evacuated out of theater under a 15-day theater evacuation policy. Thus, if 100 were admitted at OPZ 1 and 92 were evacuated to OPZ 2, 83 would be evacuated to CONUS, not 83 percent of the 92 evacuees.

least in the eyes of the user), the problem is that the output file doesn't clearly state what planning factors or input parameters the model run had used. Without the ability to easily check the values that were used in a model run, the model could be subject to a user "fishing" for the output results desired.

Whatever value MPM uses for an ALOS, this discussion highlights one of the major differences between MPM and MEPES (others will be discussed in the section describing how each model calculates requirements). In MPM's calculations of bed requirements, the ALOS is an important determinant in the calculation for the beds required at an OPZONE. The variable determines the bed-days for those who eventually return to duty, whether they began as a casualty at the OPZONE or were evacuated to it.

MEPES, on the other hand, never uses the ALOS in its calculations of beds. It would use the expected delay times and evacuation policies that we showed in table 1 to "apportion" the casualties who return to duty (RTD) on each day. As we'll show, the RTDs typically leave the bed sooner under this method and, therefore, require fewer beds. Thus, MEPES bases its requirement calculations directly on the assumed theater-level evacuation policy.

Comparing treatment and evacuation factors in MPM and LPX-MED

We've already said that LPX-MED simulates and evaluates a scenario and the resources designed to deal with such a scenario. As such, it naturally disaggregates certain variables. In addition, rather than assuming that the values of such variables are constant, it allows them to vary depending on the outcome of some assumed probability distribution. One example of such a disaggregation would be the types of casualties allowed in the model. The MPM assumes three types of casualties—WIA, disease, and NBI—which then correspond to three types of patients. LPX-MED stratifies casualties into 24 diagnosis "clusters." For each cluster, it creates a treatment protocol that contains data on lengths of stay for five acuity levels.

Another difference is the definitions of the echelons of care that each models. The MPM describes care at different OPZONEs (1, 2, and 3),

which really correspond to third, fourth, and fifth echelons. LPX-MED has all casualties pass through second echelon.

This description should indicate some of the reasons why the models are not easy to compare. Nonetheless, because we want to evaluate what each implies for the requirements process, it's important to reduce the differences as much as possible, even if only for certain "stylized" cases. In this section, we've had to make some key assumptions and aggregate certain variables to match the MPM definitions. These changes will make it easier to interpret why the models lead to different sets of bed requirements even when the casualty streams are the same.[6]

To compare variables to MPM, we found it useful to aggregate the 24 diagnosis clusters to match the three patient types in MPM as closely as possible. It turned out that LPX-MED aggregates disease, NBI, and battle fatigue casualties into an aggregate that it calls DNBI. Therefore, the closest match to the patient types in MPM will be for WIA and DNBI. In most cases, disease and NBI have similar evacuation and treatment characteristics in MPM.

To compare assumptions concerning lengths of stay, we need to distinguish between the treatment protocols in LPX-MED and the realized treatment times that result from a given run of the model. The protocols describe in general terms how long a patient should stay at a given echelon before being returned to duty or evacuated. LPX-MED provides six different kinds of treatment, such as intensive, intermediate, and minimal care, each requiring different types of beds and varying amounts of the associated medical resources.

In presenting some comparable input values, we'll start with what the LPX-MED protocols imply about the kinds of treatment and evacuation that would be observed in a run. We'll present the time required

6. One way to make the models more comparable is to run LPX-MED "deterministically." Using this option means that the model doesn't depend on draws from a probability distribution: values of those variables are set to some predetermined mid-level. For example, the acuity level assumed for every diagnosis cluster is alway "3," the middle acuity level.

for treatment at each echelon and the proportion of casualties who would be evacuated after receiving this treatment. Unlike MPM, for example, which assumes that the time in a bed at an OPZONE is given by the ALOS for RTDs and the evacuation delay for evacuees, LPX-MED doesn't use different planning factors for these two patient categories. Instead, LPX-MED applies the treatment protocols to all patients.

Table 3 presents the average time spent at each echelon based solely on the protocols. The values in the table assume that all treament specified by the protocols must be provided before evacuation can take place to a higher echelon. For WIA, the number of days spent in a bed totals about 13 in theater, but increases dramatically once the patient arrives in CONUS. For DNBI, the average time spent at each echelon totals about 10 in theater and slightly less than 4 in CONUS.[7]

Table 3. Average time spent at each echelon based on LPX-MED treatment protocols

	Average time (in days) by echelon			
Casualty type	2	3	4	5
WIA	< .1	6.9	6.0	83.5
DNBI	< .1	8.0	2.2	3.7

Table 4 presents evacuation rates, again assuming that the protocols alone dictate when patients can be moved. If the user assumes that the patient can be moved once stabilized (say, up through intensive care), we would expect the evacuation rates to be even higher than those shown in table 4. For WIAs, 98 percent of all of WIAs at second echelon would be evacuated. Clearly, although both models supposedly subscribe to the same general evacuation policy (i.e., 15 days in theater), the underlying data on which they're based are different.

7. It's difficult to compare these numbers with MPM because an MPM user can change the value assumed for the ALOS. As examples, we've observed theater-level ALOS for WIAs ranging from 9 to 19 days and for disease and/or NBI from 6 to 10 days.

Although the data in table 2 for MPM indicate at least some relationship between the evacuation policy and the evacuation rate, it isn't at all clear that there is much relationship between the two in LPX-MED's treatment data. We'll discuss this point further when we present the results of an actual LPX-MED run.

Table 4. LPX-MED evacuation rates

Casualty type	Evacuation percentages by echelon		
	2 => 3	3 => 4	4 => 5
WIA	98.0	98.0	78.1
DNBI	100.0	94.5	93.3

Once again, direct comparisons between the values in table 4 and those in MPM depend on the specific MPM run and the values chosen by the user. But, the values in table 2 provide one set of values to compare with the underlying protocol data in LPX-MED (and they are used in the test scenario we run later in our analysis).

For DNBI, the protocols suggest that LPX-MED evacuates every casualty out of second echelon, about 5.5 percent stay and return to duty at third echelon, and the remaining 94.5 percent are evacuated to fourth echelon. The theater-level evacuation rate is 93.3 percent, compared to about 38 percent in the MPM. Comparing the numbers in the LPX-MED and the MPM, it appears that LPX-MED's theater-level WIA evacuation rate is slightly lower—78 versus 83 percent—but its DNBI evacuation rate is much higher—93 versus 38 percent. The overall rate depends on the mix of casualties, but the numbers illustrate one characteristic of LPX-MED: the underlying treatment data cause the model to evacuate more casualties out of theater than does the MPM. Clearly, although both models supposedly subscribe to the same general evacuation policy (i.e., 15 days in theater), the underlying data on which they're based is different.

Because these values represent the protocols, they are unlikely to be observed in an actual run. Typically, patients will be moved before the full protocol being executed. Nonetheless, we believe they provide useful information because they put a "bound" on what will be

observed. In an actual run, the user can set the level of care required for stabilizing patients. The model assumes that evacuation can take place once the patient is stabilized. That means that the in-theater stays in an LPX-MED run would usually be less than what's presented in table 3 and its evacuation rates would usually be higher than what's presented in table 4.

To compare accurately the lengths of stay in LPX-MED to those in MPM, we have to split the patients in LPX-MED into two groups—those who RTD and those who must be evacuated.[8] Table 5 presents the average time spent at each echelon for those who are evacuated. Using the percentages from the previous table, 78 percent of the WIAs average about 14.4 days in a bed in theater and 83 days in a bed in CONUS, for a total of about 98 days in a bed. The numbers are much lower for DNBI casualties. They spend about 10 days in theater, but only about 4 in CONUS.

Table 5. Average time spent at each echelon in LPX-MED for evacuees

	Echelon			
Casualty type	2	3	4	5
WIA	< .1	6.9	7.4	83.5
DNBI	< .1	7.8	2.1	3.7

The last group we compare are those who RTD. Table 4 implied that very few casualties, whether WIA or DNBI, actually RTD in theater. Table 6 shows that WIAs who do RTD will have spent less than half a day in a theater medical facility. The table also shows that the DNBI casualties, although few in number, spend more than 18 days in a bed in theater.

8. MPM really uses the term ALOS only to refer to those who RTD at an echelon. The length of stay at an echelon for those patients who must be evacuated is equal to the assumed evacuation delay.

Table 6. ALOS for RTDs in LPX-MED

	Echelon			
Casualty type	2	3	4	5
WIA	< .1	–[a]	0.4	83.5
DNBI	–	11.7	7.6	3.7

a. Denotes no observations in this cell. From table 4, all WIAs at echelon 3 were evacuated to echelon 4.

As we said, it's not easy to compare these values with what's typically used in MPM because the MPM ALOS assumptions vary from run to run. In general, however, both evacuation rates and the time in a facility appear to be reasonably close for WIA evacuees, but much different for WIA RTDs and theater-level DNBI casualties. Specifically, LPX-MED evacuates many more of the DNBI casualties, and they spend less time in theater before moving to CONUS.

Calculating requirements

The previous section described several important planning factors, including some of the differences we've observed in the models. In this section, we want to illustrate how the models use their specific planning factors to generate a set of requirements.

We describe each model's approach to deriving a bed requirement. Further mathematical details appear in appendix A for MPM and in appendix B for MEPES.

MPM

In addition to providing a general description of MPM, we'll discuss some of the problems that we encountered when trying to duplicate the results of what we call the JOPES version of MPM. Some of the differences result from relatively subtle changes to assumptions or in the interpretation of certain key variables. Appendix A shows how we believe the underlying mathematical equations change as a result and describes two alternative versions of the model.[9] One is based directly on the "original" equations that formed the basis of the model many years ago. It is our understanding that the new MAT uses these equations to generate its bed requirements.[10] The second version is what we believe closely "mimics" the calculations in the JOPES MPM. We

9. CNA has developed a Visual Basic program that, with a simple change to one command, calculates all important variables for either alternative. It provided us with a useful tool for evaluating differences between the two alternatives and determining how their respective bed requirements change in response to changes in individual planning factors.

10. That is not to imply that Booz-Allen Hamilton, the model developer, has not made any changes either in terms of variable interpretation or to some equations. Until we can examine the new version, however, we believe that substantive changes of the sort described in appendix A probably have not been made.

can only say it mimics the calculations because, while it duplicates many of them, we couldn't duplicate all calculations (although we came a lot closer than we would have using the original equations).

How the model works

Figure 1 shows how MPM works. The three types of casualties—WIA, disease, or NBI—enter medical facilities at either OPZ 1 or OPZ 2 (the combat and communication zones). Casualties in OPZ 1 either stay in beds at the facility for some set period, given by the ALOS, before being returned to duty, or they stay in beds for the time defined by the evacuation delay before being evacuated to OPZ 2. Therefore, the number of OPZ 1 beds required on any given day depends on:

- Patients admitted today
- Patients who have been in beds and will ultimately be returned to duty
- Patients who have been in beds and are waiting to be evacuated to OPZ 2.[11]

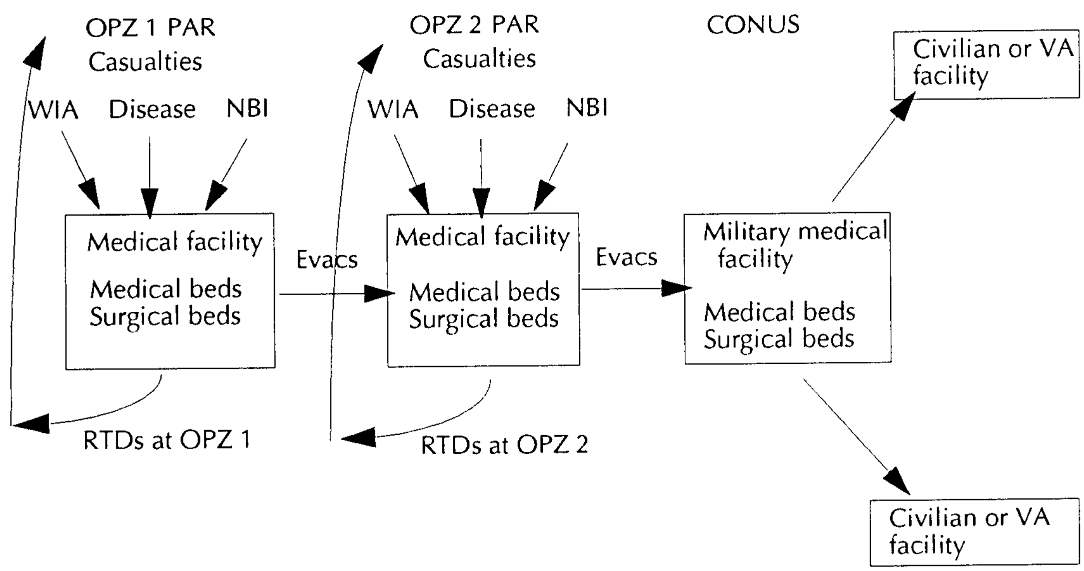
Bed requirements at OPZ 2 can be derived similarly, but with one additional complication. The flow into the facility has two sources: new casualties directly in OPZ 2 and evacuees from OPZ 1. Some of these evacuees—specifically those who RTD at OPZ 2—will remain in beds until they reach the OPZ 2 ALOS, at which point they RTD at OPZ 2. The time in beds at OPZ 2, however, must take into account the time spent waiting to be evacuated at OPZ 1. For example, if there were a 9-day ALOS at OPZ 2, but evacuees waited 3 days to leave OPZ 1, they spend only 6 additional days in beds at OPZ 2.

Those who do not RTD, but who must be evacuated out of theater to CONUS, have an additional delay period, at which time they leave the beds. Thus, at OPZ 2, both new casualties and evacuees from OPZ 1 can

11. Our figure may seem to imply that the PAR will increase in response to those who RTD. MPM doesn't adjust the PAR in this way, however. The Users' Guide acknowledges that the population at risk might be affected, but the model doesn't actually do anything with them.

return to duty or become evacuees, but the amount of time they will spend in OPZ 2 beds will vary depending on where they originated. This complicates OPZ 2 bed requirement calculations.

Figure 1. Flow of casualties into and out of OPZ 1, 2, and 3 facilities



CONUS is the third, and last, OPZONE. As in OPZ 1, there is only one flow in, the evacuees from OPZ 2, but it differs from the other two OPZONEs because no casualties originate there. Some of the evacuees stay for the ALOS defined for CONUS (less the respective evacuation delay times at OPZ 1 or 2), but those with longer lengths of stay move after an assumed delay period to civilian or VA facilities.

Our representation is meant to be simple; the actual calculations depend on several additional assumptions and input values. We have described some in the section on important planning factors; we will describe others in appendix A. Two input values we haven't yet focused on—the bed multipliers and the dispersion allowance factor—play important roles in calculating bed requirements from the flow of patients being admitted.

The bed multiplier represents the proportions used to divide an unspecified bed into the two types derived in MPM—medical and surgical. The model uses simple percentages to represent the proportion of time that a casualty is expected to require a medical or a surgical bed. Table 7 presents the assumed constant values for all three casualty types.

Table 7. Medical care requirements—beds

	Medical	Surgical
WIA	0.2	0.8
Disease	0.9	0.1
NBI	0.3	0.7

MPM assumes a dispersion allowance at each OPZONE, which translates into a multiplicative factor in the OPZONE's bed requirement equation. It is meant to increase the bed requirement by a percentage from the number of patients calculated at any OPZONE. It can represent uncertainty (the "fog of war") or anything else that might account for an increased need for beds over and above the number of patients. As an example, at OPZ 1, MPM runs usually assume a 20-percent allowance, which translates into a factor that multiplies the bed calculation by 1.25. MPM uses this factor in its requirement calculations (as does MEPES), but LPX-MED does not.

Problems encountered in reproducing MPM results

Before leaving this section, we list some of the problems we encountered in our efforts to reproduce MPM's calculations:

- The underlying computer code is essentially unavailable for verifying its calculations. This is because of the model's age and the way it was written to be part of JOPES.
- Verifying its calculations is also made more difficult because of the way MPM outputs its results. It presents only a 10-day peak and average value for many variables, including bed requirements. The model must calculate the numbers; it's only the output listing that limits what's shown.

- The model is unclear regarding assumptions made about the specific day that an evacuee is moved, leaves the bed, and arrives and occupies a bed in the next OPZONE. The same is true for RTDs.
- Default tables provide more information (sometimes irrelevant) than the specific run requires. There is often no clear statement of which input variables were actually used in the model run, particularly when user-supplied values have been assumed.
- Rounding is used throughout, without any clear statement of the rules assumed.

We've been able to overcome some of the problems simply through trial and error. In other words, we assume a value, try it in the calculations, and, if it works and we derive the same number as in the MPM output, we assume that we have the right equation and input values. We hope that any new wartime medical requirements model will make it easier to understand how it generates its results.

MEPES

MEPES is another calculator type of model whose development began in the early 1990s to replace MPM. It's similar to MPM in that it was designed to forecast the theater medical resource requirements based on the warfighting scenario. However, MEPES was designed to generalize the MPM assumption of only three OPZONEs.

Despite all of the efforts to create a new and improved calculator model, it seems unlikely that MEPES will ever be used to generate a set of requirements.[12] Even though the full version of MEPES might not be used, its method for calculating a requirement might serve as a front-end to LPX-MED. For that reason, we will describe briefly how

12. The Joint Staff feels the model requires various corrections, testing, and validation before it can be used on the Global Command and Control System (GCCS), all of which costs money that does not appear to be forthcoming.

it differs from MPM, and in a later subsection we'll contrast the requirement numbers it generates for beds with those in MPM.

Multiple OPZONEs and other improvements

MEPES is like MPM in that it extracts essential data elements from Time-Phased Force and Deployment Data (TPFDD) for defining the PAR. Unlike MPM, however, which defines the PAR geographically into only three OPZONEs—combat, communication, and CONUS—MEPES defines the PAR in up to six sectors in each of up to five OPZONEs. Both allow an OPZONE to also be defined by functional type—that is, combat or combat support.

The introduction of as many as 30 different combinations of sectors and OPZONEs gives MEPES one important advantage over MPM. For example, Europe might be introduced as an additional OPZONE to the three in MPM. This European OPZONE could then be further sectored into different geographic areas (e.g., the Norwegian, German, or Spanish regions). The additional OPZONEs/sectors would also allow different combat-related OPZONEs, each with potentially different casualty rates. The planner can design a more realistic battlefield scenario when the casualty rates don't have to be applied to the entire OPZONE, as it is in MPM.[13]

The potential tenfold increase in OPZONEs/sectors is probably the most significant difference between MPM and MEPES. Other improvements include (at least conceptually) an additional two casualty types to the three generated for MPM—WIA, disease, and NBI. MEPES adds battle fatigue and unconventional warfare. For a few reasons, this improvement is minor. It's not clear the services have actually derived values for these two, particularly for unconventional warfare, and any calculator model, including a rewritten version of MPM, should be able to incorporate a few more casualty rates.

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13. MEPES has been criticized for being too restrictive in the way it applies its casualty rates. The rates are tied directly to the five combat intensity levels, and the user cannot change them.

In a similar manner, MEPES also generates requirements for additional bed types. Rather than the medical-surgical split in MPM, MEPES generates a requirement for intensive care, intermediate care, minimal care, and convalescent care by OPZONE/sector. Although this split does not match the split in LPX-MED precisely, it's a lot closer than the two types in MPM. Any calculator model that will be used in LPX-MED must provide a requirement for the same bed types that LPX-MED will evaluate later in the run.

Other stated improvements or enhancements in MEPES seem unrelated to the bed requirement calculation. Without the model being run and its output compared to the output in MPM, it's difficult to compare every characteristic of the two models directly. The implications for bed requirements can be ascertained, however. We turn next to MEPES' reliance on evacuation policy variables in determining a bed requirement.

Role of evacuation policy in bed determination

On page 13, table 1 showed the evacuation policy for three OPZONEs, which is the typical case in MPM. Evacuation policies determine the distribution of patients and their associated medical requirements throughout the medical system.[14] Table 8 shows how MEPES might generalize this to five OPZONEs and presents an assumed evacuation policy associated with each.

What's different in MEPES' calculations of requirements? As we said, MEPES doesn't define an ALOS for those who RTD at an OPZONE. It starts by calculating the total number of daily admissions less the sum of the total number of evacuees and the total number of those who died in hospital (DIH). The model has to distribute them over some period of time and over an OPZONE. As in MPM or LPX-MED, someone can be a casualty at one OPZONE but RTD at a higher OPZONE. MEPES tracks the two types of RTDs. It refers to the first type as a "local RTD"—a patient who is admitted and returned to duty

14. Planners define the evacuation policies and can change them over the duration of the OPLAN. In MEPES, the planner can change them up to 23 times. Those evacuated usually move rearward one OPZONE.

at the same OPZONE. It refers to the second type as a "transfer RTD"—a patient who was admitted in one OPZONE but, because of the evacuation policy, was evacuated and returned to duty at a rearward OPZONE.

Table 8. Evacuation policy example in MEPES

OPZONE	Theater/CONUS	Evac policy (EP)/ evac delay (ED)
1	T	7/3
2	T	15/5
3	T	30/7
4	C	60/10
5	C	60/59

The concept of different types of RTDs is not different from MPM or LPX-MED. But rather than discuss how long each stays in a bed based on ALOS or treatment times, MEPES distributes them over time. It distributes local RTDs from the following formula:

$$\text{Distribution percentage} = \frac{1}{\text{ED} - 1} \quad . \tag{1}$$

Suppose we want to calculate local RTDs at the various OPZONES. Substituting the delay times from table 8 into the equation leads to distributing them over 2 days at OPZ 1 (i.e., 50 percent on each day), 4 days at OPZ 2 (or 25 percent), 6 days at OPZ 3, and so on. The model starts the day after the admission. If there were 100 RTDs to be distributed, half, or 50, would return on C+1 and the remaining 50 on C+2.

The distribution of transfer RTDs is more complicated. Here, the distribution over time follows the following formula:

$$\text{Distribution percentage} = \frac{1}{[\text{EP} - \text{Sum of previous EDs}] - 1} \quad . \tag{2}$$

Using the same example for OPZs 1 and 2 from table 8, the distribution of transfer RTDs would be found after substituting 15 for EP and

3 for the sum of the previous EDs, which would lead to 1/[12] - 1, or 1/11. At OPZ 3, the formula for the distribution would lead to 1/[30-8] - 1, or 1/21. Clearly, as evacuees move further and further rearward, the distribution period grows larger as long as the evacuation policy grows larger than the assumed evacuation delay. Some of the numbers may not seem entirely intuitive, but it is a way to ensure that all RTDs leave the medical facility without stating any assumed treatment time.

Can we say much about the difference in beds required from the other models? We provide a specific example in appendix B to illustrate the differences that would be caused by the same assumed casualty stream. We developed a MEPES-type spreadsheet version, using the same scenario as the MPM test run, so we can compare results from our MEPES run with the MPM results.[15]

In general, however, we can deduce some of the resulting implications for bed requirements. MEPES starts distributing the RTDs almost immediately (the next day after admission), while MPM assumes that those admitted on a given day have to wait for the ALOS before leaving (and when they do leave, they do so all at once). Clearly, at the forward echelons, OPZs 1 and 2, with relatively large evacuation delays relative to the evacuation policy, we would expect that MEPES would return patients faster and, therefore, require fewer beds. At rearward OPZONEs, it's more complicated, but we would infer that the approach taken in MEPES, for the typical three- or five-OPZONE evacuation policy, would lead to a reduced requirement.

LPX-MED

As we described earlier, LPX-MED is not a requirements calculator model but rather a simulation model that determines the sufficiency of the available resources. If the available resources are not sufficient at a site, the model flags this "choke point." Because the model is not

15. The numbers we generate from a "MEPES-like" model is a CNA conceptualization of the model and, therefore, somewhat simplified when compared to the original. Nonetheless, it should illuminate most of the important differences between MEPES and MPM.

an optimization model, it does not guarantee that resources will be used efficiently or relatively evenly. Choke points can occur at a given site even though there might be sufficient assets in theater.

To generate requirements from this model, the Joint Staff directed the model developers to run the model with very high levels of resources and use the estimates of resources used as the requirements estimates. In exploring LPX-MED, we have run a "megafacility" scenario.

Medical network

To set up LPX-MED for a run, the user must input the medical network and resources available at each echelon (see [3] for more details). The user inputs the number of medical facilities (echelons 2 through 4 and CONUS) and their relative locations (distances separating each facility). The user also inputs the resources available at each facility in terms of beds, staffing and medical supplies, and organic evacuation assets. The user connects the medical network by creating evacuation routes between the facilities, which will dictate the flow of patients through the network. In addition, the user can add inorganic evacuation routes that follow a fixed circuit flight plan, picking up and discharging patients at each stop.

Casualties

To start the model, the user must input a combat scenario that will generate a casualty stream. Based on the combat scenario (the location of units, the number of personnel, and the combat intensities and the casualty rates for each day), the model generates a stream of casualties. To estimate the number of casualties in a period, the model multiplies the current PAR for each unit by the appropriate casualty rates, given the unit's level of combat intensity. Although the model allows the user to input different casualty rates for WIA, battle fatigue, disease, and NBI, these rates ultimately are aggregated to two rates, WIA and DNBI, to generate a patient stream.

Treatment

Diagnosis clusters

The model translates the casualties into a patient stream by assigning casualties to 24 diagnosis clusters. The model make these assignments based on the probability of frequency for the regional scenario.[16] These probabilities are among the few variables that are fixed and contained within the model rather than being set by the user.[17] When run in simulation mode, the model also assigns an acuity level (from 1 to 5) that is drawn from a uniform distribution for each patient. In deterministic mode, the model assigns acuity level 3 (the middle acuity level) to all patients.

Treatment protocols

Each diagnosis cluster has an associated treatment protocol. The treatment protocol data are also contained within the model and cannot be altered by the users. The treatment data are derived from the patient condition codes (PCCs) and treatment times from the Defense Medical Standardization Board's Deployable Medical Systems (DEPMEDS) database. LPX-MED collapses the approximately 350 PCCs in DEPMEDS to 24 clusters. For each diagnosis cluster, there are five treatment protocols, reflecting the care levels required for each acuity level. The varying acuity treatment times are based on averages across the original set of PCCs that make up each cluster.

Table 9 presents an example of LPX-MED's treatment protocol data. The treatment protocol data describe, for each diagnosis cluster, the quantity and type of care the patient requires at each echelon of care. The quantity of care is denoted in hours. The type of care is divided into five categories: ER/triage/X-ray/lab, OR, ICU, intermediate care ward, and minimal care ward. Echelon 2 is the model's starting

16. The patient category probabilities were based on estimates from the Army Medical Department (AMEDD) Center and Schools, which developed a set of estimates for each regional scenario. Our runs use the estimates for the Southwest Asia Scenario.

17. WIA and DNBI have separate sets of patient condition probabilities.

point for treatment. At echelon 2, only a standard amount of triage of 1.5 hours is given to all patients.

Because the protocols represent average treatment times for a set of conditions, they do not always describe a logical sequence of care for a given person. Many of the protcols describe only a few hours of care at an echelon. For example, in table 9, the acuity 1 protocol suggests that all patients be evacuated back to echelon 4 to receive 12 minutes (0.2 hour) of care. To have such a low average care requirement at echelon 4 implies that the majority of the underlying DEPMEDS PCCs require no care at echelon 4. However, LPX-MED would evacuate all these patients to echelon 4.

Table 9. Sample LPX-MED treatment protocol—chest/abdomen wounds

		Treatment time (in hours)				
Echelon	Bed type	Acuity 1	Acuity 2	Acuity 3	Acuity 4	Acuity 5
2	Triage	1.5	1.5	1.5	1.5	1.5
3	ER/triage/X-ray/lab	1.6	1.8	1.9	2	2
	OR	1.2	1.8	2.3	2.9	3.5
	ICU	10.9	26.2	41.4	56.6	69.1
	Intermediate ward	5.2	21.1	37.1	53.1	69.1
	Minimal ward	0	0	65.3	154.1	242.9
4	ER/triage/X-ray/lab	.2	.6	1	1.5	1.9
	OR	0	.2	.5	.8	1.2
	ICU	0	0	.1	2.4	4.7
	Intermediate ward	0	75.3	161.3	247.3	333.3
	Minimal ward	0	81.8	255.5	429.1	602.8
5	ER/triage/X-ray/lab	0	.1	.2	.4	.5
	ICU	0	0	42.3	91.6	140.8
	Intermediate ward	0	38.9	114	189	264.1
	Minimal ward	0	261.7	695	1128.4	1561.8

Other cases probably deserve further examination to ensure that the underlying protocols themselves are reasonable from a medical standpoint and that the aggregation into the LPX-MED clusters leads to sensible treatment guidelines for that general condition. Accessing

the treatment data for each of the 24 casualty clusters within LPX-MED can be done, but not easily. Therefore, we've listed them all in appendix C. Making them more visible to potential users can help in the process of ensuring their reasonableness and suitability in theater-level requirements models.

Why are the cluster treatment times associated with the protocols so important? They are important because treatment times translate directly to bed requirements. For example, a treatment requirement of 6 hours of ICU care translates into a requirement for 6 hours of an ICU bed. The model allows a patient to stay in a bed for a fraction of a day. The model calculates total bed requirements by summing across patients and bed types. The model translates bed-hours into bed-day requirements by dividing these sums by 24.

Factors affecting lengths of stay

The treatment protocol is only one of several variables that determine the actual level of care the patient receives at a given echelon. The amount of care given to a patient at an echelon is determined by the combined effect of three factors:

- The treatment protocol
- The evacuation policy (set by the user)
- The stabilization level of care (set by the user).

Evacuation policy

The evacuation policy defines who should be treated and returned to duty versus who needs to be evacuated to a higher echelon. If the patient can finish treatment in less time than the evacuation policy, the model will treat the patient and return him or her to duty at the current echelon. For example, let's assume the evacuation policy is 7 days between echelons 3 and 4. If the patient's treatment protocol requires 4 days of care at echelon 3 and no further treatment at a higher echelon, the model will treat the patient and return him or her to duty at echelon 3.

We find that the treatment protocols typically dictate that most patients be evacuated back to CONUS. This occurs because the

treatment protocols for the echelons usually require either relatively long lengths of stay (exceeding the standard evacuation policy) or additional care at higher echelons. Either situation will cause the model to evacuate the patient to the next echelon. Returning to our previous example, suppose the treatment protocol called for the same 4 days of care at echelon 3, but also called for an additional 2 days of care at echelon 4 (and no care at echelon 5). Under these circumstances, LPX-MED would evacuate the patient to echelon 4 even though the total treatment time (at 3 and 4) was less than the 7-day evacuation policy. This occurs because LPX-MED does not "read ahead" to the next echelon when evaluating treatment requirements. Because many of the treatment protocols call for treatment at CONUS, the model evacuates most patients back to CONUS irrespective of the evacuation policy. This point is important and implies that policy-makers who regard evacuation policy as an important element in the requirement process may want to reconsider their reliance on LPX-MED and its underlying data.

Stabilization level of care

The stabilization level of care is also an important factor in determining the amount of care a patient actually gets at a particular echelon. The stabilization level of care defines when the patient is stable enough to be evacuated. Once the patient has completed the stabilization level of care, the model considers the patient to be a candidate for evacuation. Unless the patient is slated to be returned to duty based on the evacuation policy, the model will evacuate the patient back to the next echelon upon completing the stabilization level of care. The remaining care described by the treatment protocol for that echelon will be "carried forward" and given at a higher echelon. The total amount of care described by the treatment protocols will be given somewhere within the health care system. But, depending on the values of the other key variables, this care may be given at a higher echelon than the protocol describes.

Given the influence of the other key factors, the treatment protocols plus the care carried forward serve as an upper bound for the level of care provided at an echelon. Patients cannot receive more care at an echelon than that described by the treatment protocol plus the care carried forward (i.e., the model doesn't read ahead).

The stabilization level of care is a powerful variable in determining at what echelon the care actually gets delivered. Table 10 shows the effect that changing the stabilization level of care from minimum care ward to ICU has on the percentage of patients evacuated to the next echelon. It shows that LPX-MED evacuates many more patients back to CONUS when the user sets stabilization through ICU.

Table 10. Evacuation rates under alternative stabilization levels

Stabilization level	Casualty type	Rate of evac. (%) to next echelon 2-3	3-4	4-5
Minimum care ward[a]	WIA	98.0	98.0	78.1
Minimum care ward	DNBI	100.0	94.5	93.3
ICU[b]	WIA	98.0	100.0	100.0
ICU	DNBI	100.0	100.0	94.5

a. Must complete treatment through ER/triage/X-ray/lab, OR, ICU, intermediate care, and minimum care.

b. Must complete treatment through ER/triage/X-ray/lab, OR, and ICU.

Table 11 shows that lowering the stabilization level of care also radically reduces the average stay at echelons 3 and 4 and has a mixed impact on the average stay in CONUS. Because patients are evacuated after ICU, the average stay at echelon 3 and 4 falls.[18] In contrast, the effect in CONUS is less intuitive. We find that setting the stabilization level of care through ICU causes the model to evacuate back to CONUS many patients who, for their recuperation, do not require long lengths of stay. Those patients with relatively short stays lower the overall average stay in CONUS.

18. If the evacuation policy is longer than the total care requirement at 4 (carry forward from 3 plus additional care at 4), this care will be executed at echelon 4. Alternatively, if the policy is shorter than the care requirement, the patient will only be stabilized at 4 and all remaining care will be provided at echelon 5, as table 12 shows.

Table 11. Average time in facility under alternative stabilization level

Stabilization level	Casualty type	Average stay (in days) by echelon			
		2	3	4	5
Minimum care ward	WIA	< .1	6.9	6.0	83.5
Minimum care ward	DNBI	< .1	8.0	2.2	3.7
ICU	WIA	< .1	1.2	0.3	78.0
ICU	DNBI	< .1	0.4	0.7	13.2

How LPX-MED evacuates patients

LPX-MED evacuates patients after they have completed the stabilization level of care at an echelon or to alleviate choke points. When a patient arrives at a facility, the model evaluates whether the facility has sufficient resources to treat the patient within the time allowed.[19] If the patient cannot be treated at the current facility and an appropriate evacuation asset is available, the patient will be evacuated immediately. Alternatively, once a patient has been treated and has completed the stabilization level of care, he or she becomes eligible for evacuation.

The model will move the stabilized patient to a higher care echelon as soon as an evacuation asset is available. LPX-MED determines evacuations solely by patient eligibility and the availability of evacuation assets. The model does not consider whether the destination facility is truly able to treat the patient.

When a patient is eligible to be evacuated, the model places the patient in an evacuation queue. While patients are waiting to be evacuated, they do not use a bed or other medical resources. We think this is one shortcoming of the model. Often patients being evacuated are not ambulatory. In fact, the model accounts directly for the fact that many patients will require litters for evacuation, and it matches these

19. Each diagnosis cluster has an associated maximum number of hours a patient can wait for treatment. If this waiting time is exceeded, a choke point will occur, signaling insufficient resources.

requirements to the available evacuation assets. It seems contradictory to have patients evacuated in litters but not to use resources while they wait for evacuation. In addition, if the user set the stabilization level of care to after ICU (the default level), many of the evacuees will still require a great deal of care while waiting.

Bed-day counter

As part of its output, LPX-MED gives a measure of the number of beds used at each echelon each day. This is the counter model developers use to determine bed requirements. In addition, all other facility resource use (staff and supplies) depends directly on how the model counts beds because bed use drives the use of staff and supplies. However, the calculation of beds by the counter is not apparent to the user. In particular, we were concerned by our observation that the bed-day counter gave patients from 4 to 6 hours of bed time at echelon 2 even though the treatment time is a fixed 1.5 hours at this echelon and no patients were waiting to be evacuated. Does this counter reflect time in treatment or time spent in the facility (including waiting time) or something else?

In exploring how LPX-MED calculates its bed-day counter, we discovered that this counter does not match the patient flow data. As an auxiliary output, the model produces a patient flow file that tracks all patient status changes. We used these data to compare the model's bed-day counter to the time the patient spends in treatment, in the facility and total time in the system (including evacuation time). Under the "megafacility" scenario, with its assumption of more than sufficient resources, no one waits to be evacuated. As table 12 shows, we found that time in treatment, time in facility, and total time in the system all closely correspond, but none of these measures matched LPX-MED's bed counter.

From this exploration, we conclude that the LPX-MED bed-day counter approximates the time the patient spends in treatment (recall that in our scenario no one waits to be evacuated) but that it is not calculated directed from the patient flow data.

Table 12. Measures of total bed-hours (in thousands)

	Time in treatment	Time in facility	LPX-MED bed counter	Time in system[a]
All patients	45.7[b]	47.1	47.0	48.5
Patients who RTD	37.6	38.7	n/a	40.3

a. Includes evacuation time.
b. Estimates based on the differences observed between time in treatment and time in facility for patients returned to duty. We could not directly observe the time in treatment for patients who were still receiving treatment at the end of the scenario.

Deterministic versus simulation

LPX-MED can be run two ways: deterministically or as a simulation. When run in deterministic mode, the user sets all the input variables before running the model. In contrast, when run as a simulation, several variables are determined by random draws from a distribution rather than being preset. These simulated variables include:

- Patient arrival times from combat
- Diagnosis acuity (5 levels)
- Evacuation waiting time
- Percentage of ambulatory evacuees.

We have found that, for the same scenario, the simulation produces significantly lower bed requirements than the deterministic model. Table 13 shows the bed-day difference between a simulation and a deterministic run of our megafacility scenario. The total bed requirements for the simulation are lower than they are for the deterministic run because of the much lower requirements at echelon 4.

Table 13. Total bed day-requirements (120-day scenario)

	Echelon				
	2	3	4	5	Total
Deterministic	307	1,383	16,926	28,653	47,286
Simulation	309	2,328	8,116	32,438	43,191

Why does the simulation produce a lower bed requirement? We found that varying the acuity level has a significant impact on bed-day requirements. In the deterministic run, the acuity level is always set to 3, the middle level. In the simulation, the acuity level varies from 1 to 5, based on draws from a distribution. As we showed in table 9, the treatment times for a given diagnosis vary greatly with acuity level. By simulating the acuity level, the user is increasing both the number of short-stay and very long-stay cases. Although the model returns about the same number of people to duty in both the simulation and deterministic runs, the simulation returns patients to duty faster. Table 14 shows that the simulation returns more patients to duty at echelons 2, 3, and 4, which results in lower bed requirements. Because we only ran a 120-day scenario, we don't capture the longer stays of the very acute patients in the simulation (the bed requirements are truncated at day 120).

Table 14. Numbers of patients returned to duty by echelon

	2	3	4	5
Deterministic	5	0	111	2,066
Simulation	47	6	299	1,807

Spurious results from LPX-MED

In exploring LPX-MED, we have found numerous instances in which the model produces unexpected and spurious results. These unexpected and spurious results range from minor glitches to more serious problems. Some examples include:

- Patients languish in the evacuation queue.
- The model attempts to evacuate patients from CONUS.
- Patients all flow through one evacuation route.
- The model accepts erroneous inputs and provides virtually no error or warning messages.

We found that when we stressed the model by significantly increasing the number of patients, the model stopped evacuating patients but

did not indicate a choke point. In essence, the model left the patients languishing in the evacuation queue. We ran a short 5- day scenario, which generated 496 patients on the first day and no casualties after that. The medical network consisted of a single facility at each echelon. Each facility had more than sufficient staff, bed, and supply resources but limited evacuation assets. Echelon 2, the starting echelon, had one Blackhawk helicopter for evacuation.

Table 15 presents the daily status report for echelon 2. Clearly, there were not enough evacuation assets at echelon 2 to handle the volume of patients, yet the model did not flag a problem. The table shows that the model simply stopped evacuating patients after the first day. The model basically held these patients in limbo, neither treating them (they do not use bed-days while in the evacuation queue) nor evacuating them.

Table 15. Daily patient status report for echelon 2

Day	Patients admitted from combat	Patients evacuated	Patients awaiting evacuation	RTD	Bed-hours
1	496	10	476	10	744
2	0	0	476	0	0
3	0	0	476	0	0
4	0	0	476	0	0
5	0	0	476	0	0

Under several scenarios, we observed the model attempting to evacuate patients from CONUS even though CONUS was the final stop in the medical network. The model reported an evacuation asset shortage at CONUS and flagged a choke point. This is clearly a spurious result because CONUS was not linked to a destination site.

We found that the model often evacuates patients only through the first priority evacuation route, even when alternative routes are given. We ran a scenario in which patients could be evacuted to two alternative destination facilties from echelon 2. The model requires that the evacution routes be given different priorities. We found that the

model evacuated virtually all the patients through the higher priority route. This caused a resource shortfall at the destination facility. The model did not route patients to the echelon 3 facilities efficiently, but rather overloaded one facility while hardly using the other. In fact, we found it very difficult to force the model to flow patients to the alternative facility. To get the model to use the second facility, we had to close the first-priority evacuation route to specific diagnosis clusters. Because the model does not optimally use resources, shortfalls may reflect a resource misallocation rather than a true resource deficit.

LPX-MED gives virtually no error messages or warnings. In addition, we have found that it accepts invalid data for many of the input fields. For example, the user can control patient arrival times by inputting the percentage of patients arriving from combat during each quartile of the day. These percentages should total 100 percent. However, LPX-MED will accept, and run without any error messages, percentages that do not total 100.

Although many of these problems are not individually that serious, we are concerned that we have encountered so many different problems in LPX-MED. Given these problems, we believe that the model needs further testing for the user to feel confident in its results.

Comparing model outputs

Earlier sections have provided discussions of the important planning factors in each model—where they're similar, where they're different—and the conceptual relationships that they use to calculate a bed requirement. In this section, we turn from discussing conceptual issues to what happens when they actually calculate a requirement for a given scenario.

We evaluated the models using the same scenario—an unclassified and simple but illustrative one—to compare their respective bed requirements. We described the scenario briefly in the section on MPM, and we provide a few more details in appendix A. For MPM, we used our (Visual Basic) version of it to generate the bed requirements (see the appendix for more details and a complete accounting of the differences between our version and the JOPES MPM).

All three models begin with the same PAR and casualty stream. The scenario generates a constant and relatively high number of casualties throughout the 90-day period—75 WIAs and 46 DNBIs per day. We could present their respective results in a three-way comparison; however, because there are many more similarities between MPM and our rather stylized version of MEPES, we'll compare the implications for bed requirements from these models first. Then we'll proceed to compare the bed requirements derived from running MPM and LPX-MED (again, assuming the same scenario).

We will make one final comparison between MPM and LPX-MED, only now focusing on the underlying data from the latter model. We will summarize the underlying LPX-MED treatment data, including such planning factors as evacuation rates, delay times, and ALOS for RTDs, but use them as input values for MPM. Our example shows that some, although not all, of the differences in the two models can be explained by differences in the assumed input values.

MPM and MEPES

Scenario and planning factors

As we've said earlier, MPM and MEPES represent similar kinds of calculator models. MEPES was developed to overcome some of the restrictions found in MPM. When we compared bed requirements in each model, we focused on what we believe is the most important distinction between the two—how the model counts beds for those who return to duty. We're not trying to minimize other differences, but, for the simple scenario assumed, this one characteristic is probably the most significant difference between the models.

Briefly, the scenario assumes the same PAR and casualty rates for each model at OPZs 1 and 2. Given the assumed PAR and casualty rates, admissions for all three casualty types remain constant, as do the number of evacuees and RTDs (at least in steady state). The timing of events is different, specifically for RTDs. Table 16 lists the important planning factors assumed for the run.

Table 16. Planning factors in MPM—MEPES test scenario

Factor	OPZ 1	OPZ 2
Evacuation policy	7 days	15 days
Evacuation delay	3 days	5 days
Evacuation rate	.92 for WIA, .67 for DNBI	.83 for WIA, .38 for DNBI
ALOS for RTD[a]	5	9 for WIA and NBI, 6 for disease
Bed multiplier[b]	.2 (.8) for WIAs, .9 (.1) for disease, .3 (.7) for NBI	.2 (.8) for WIAs, .9 (.1) for disease, .3 (.7) for NBI
Dispersion factor	1.25	1.18

a. Not relevant for MEPES, which distributes RTDs based on evacuation policy and delay time.

b. We used the same medical and surgical parameters (in parentheses) in each model.

When possible, we tried to keep those factors constant that did not highlight the major differences between the models. Although we wanted to include values for OPZ 3 (i.e., CONUS), we weren't always

sure what values for some variables were actually used in the MPM run. We experimented to some extent, but it was clear that we needed more information on the inputs the run assumed. In the next set of comparisons, between MPM and LPX-MED, we will use the results from the actual MPM run for CONUS.

Model outputs

Table 17 presents the results of our runs for the peak number of steady-state medical and surgical beds over the period. In OPZ 1, the two models lead to modest differences—MPM calculates a requirement for 418 beds, and MEPES calculates a requirement for 374 beds. In other words, MEPES states a requirement for about 11 percent fewer beds. At OPZ 2, there are differences as well. MPM calculates a requirement for 751 beds, but the MEPES requirement is for only 682, or a decrease of just over 9 percent.[20]

Table 17. Comparing theater-level peak bed requirements

	MPM			MEPES		
	Medical	Surgical	Total	Medical	Surgical	Total
Echelon 3	155	263	418	133	241	374
Echelon 4	244	507	751	224	458	682

In this example, the reason for the drop is relatively simple. First, for OPZ 1, those casualties who must be evacuated to OPZ 2 face the same delay in both models and would, therefore, require the same number of beds. The bed requirement is different, however, for the RTDs. The 3-day delay at the OPZONE means that one-half return on the day after they were casualties and half the day after that. The implication is that those who return to duty average 2.5 days in a bed.

20. Although we could have used the MPM values, we felt it would be better to compare what we believe are the same factors one would use in each model. As shown in appendix A, our version of MPM matched the actual MPM run's values for beds at OPZ 1, but was slightly higher at OPZ 2 (751 versus 738 beds).

This is one-half of the 5 days assumed as the ALOS for RTDs in MPM. That explains the lower bed requirement at OPZ 1.

The lower requirement in MEPES at OPZ 2 is also a result of the smaller length of stay in a bed for those who return to duty. MEPES distributes local RTDs over 4 days, which means that the casualties on day t have all returned to duty by day $t + 5$. Contrast this with MPM, where they remain in a bed until day $t + 9$ if a WIA or NBI casualty and until day $t + 6$ if a disease casualty. For transfer RTDs, the difference in time spent in a bed is a bit more complicated, but the end result is similar: MPM will usually keep them in a bed longer, which means the bed requirement is larger—almost 10 percent larger in the example we've presented.

LPX-MED and MPM

Scenario and planning factors

We used the same scenario to compare MPM and LPX-MED. Given the same combat scenario, the models generate virtually the same patient stream, with differences due to different rounding rules.

Table 18 summarizes the main assumptions we used in running the models. For MPM, we repeat several of the factors from table 16. For LPX-MED, we set up a medical network that consisted of one very large facility at each echelon. We gave the facilities more than ample resources, eliminating the possibility of resource shortages. Because there were excess evacuation assets, no patients waited in the evacuation queue.

Model outputs

MPM and LPX-MED produce very different estimates of bed-day requirements for the same combat scenario. Table 19 presents MPM and LPX-MED peak bed-day requirements. LPX-MED produces significantly lower in-theater requirements than MPM—62 percent fewer for the deterministic run and 68 percent fewer for the

simulation—and dramatically higher CONUS requirements—about 2.7 times greater for either the deterministic or simulation run.[21]

Table 18. Planning factors in MPM–LPX-MED test scenario

Inputs	MPM	LPX-MED
Evacuation policy		
From 2 to 3	n/a	2
From 3 to 4	7	7
From 4 to 5	15	15
From 5 to civilian	30	n/a
Stabilization level	n/a	after ICU
Theater ALOS		
WIA	9 days	n/a
Disease	6 days	n/a
NBI	9 days	
Evacuation delay	3 days at OPZ 1 5 days at OPZ 2	n/a
Percentage evacuated		
From 3 to 4	.92 for WIA, .67 for DNBI	n/a
From 4 to 5	.83 for WIA, .38 for DNBI	n/a

Table 19. Comparing peak bed requirements–all echelons

		LPX-MED	
Echelon	MPM	Deterministic	Simulation
3	418	56	75
4	751	393	295
5	1,779[a]	4,999	4,427
Total	2,948	5,448	4,797

a. The MPM value is from the actual JOPES MPM run.

Why do these estimates differ? We believe that several main factors drive the difference in bed requirement estimates between the two models. These factors are:

21. Although we would like to explain the differences in the two models for CONUS beds, we are limited by our lack of information on the input parameters used by MPM. One potentially important piece of information is whether any care was provided by CONUS civilian hospitals.

- LPX-MED treatment data require less care in-theater and more in CONUS than do MPM treatment data.
- Setting the stabilization level below the minimum care ward in LPX-MED further reduces in-theater care and drives more rapid evacuations.
- LPX-MED evacuates a much higher percentage of patients back to CONUS than does MPM. As we'll see, this is especially true for DNBI patients.
- MPM rounds bed-days to whole days, whereas LPX-MED keeps track of fractions of a day.
- MPM has a dispersion factor that increases the bed requirements by 25 percent at echelon 3 and by 18 percent at echelon 4.

As we discussed earlier, the treatment data underlying the two models are very different and are powerful drivers in both models. LPX-MED assumes generally shorter in-theater treatment times than does MPM. In addition, in LPX-MED patients can be evacuated after reaching stabilization, which further reduces the in-theater care requirements. As a result, the amount of time patients stay in-theater is much shorter in LPX-MED than in MPM.

Table 20 compares the average amount of time patients (both RTDs and evacuees) spend at each echelon in the two models. To calculate the average time patients spend at each echelon in MPM, we took an average of the ALOS for RTDs and the evacuation delay for evacuees, weighted by the evacuation rate associated with the type of casualty. Remember that the total number of patients includes evacuees from echelon 3 and new casualties at echelon 4. One complication in the calculation results from the adjustment in the ALOS at echelon 4 to account for the time that evacuees from echelon 3 spent in a bed there (which is equal to the evacuation delay plus 1 day).

As the table shows, for either type of casualty, in LPX-MED patients spend significantly fewer days in-theater (at echelons 3 and 4) than in MPM—2.4 days for WIAs (9.0 for DNBI) in LPX-MED versus 10.2 days (10.0 for DNBI) in MPM. For roughly the same number of casualties entering theater-level medical facilities, the lower average time that

patients spend there results in much lower bed requirements at echelons 3 and 4.

Table 20. Average time patients (evacuees and RTDs) spend at each echelon (in days)

	MPM		LPX-MED	
Echelon	WIA	DNBI	WIA	DNBI
3	4.1	4.3	1.0	0.7
4	6.1	5.7	1.4	8.3
5	a		40.4	4.2

a. Depends on the assumed CONUS retention policy/schedule, which we could never determine accurately.

Even with the same evacuation policy, we find that the underlying treatment data cause LPX-MED to evacuate a higher percentage of patients back to CONUS than does MPM. LPX-MED evacuates more patients, and does so more rapidily, than MPM. In essence, LPX-MED mimics a system in which patients are moved out of theater as soon as possible and very few patients are returned to duty. Table 21 compares the percentage of patients evacuated by the two models. In LPX-MED, virtually all patients were evacuated back to CONUS . In contrast, MPM has a significant number of patients, particularly DNBI, returning to duty at echelons 3 and 4.

Table 21. Percentage of patients evacuated at each echelon

	MPM		LPX-MED	
Echelon	WIA	DNBI	WIA	DNBI
3 => 4	92	67	100	100
4 => 5	83	38	100	94

Another major difference between the two models that has a large effect on the bed requirement is how they apply rounding rules. MPM tracks bed-days as whole days, whereas LPX-MED tracks bed-days down to a tenth of an hour. LPX-MED rounds bed-days to whole

numbers only after they have been summed across patients. We have found that the level at which the model rounds bed-days has a significant effect on the final bed requirement estimates. We recalculated the bed requirements in LPX-MED using the patient tracking information and rounded the bed-days to whole numbers each day for each patient. Based on these calculations, we reestimated the bed-day requirements for the scenario. As table 22 shows, we found that the requirements in LPX-MED rose significantly with this change.

Table 22. LPX-MED bed-day requirements under MPM assumptions

Echelon	LPX-MED–rounded[a]	LPX-MED–dispersion factor
3	213	70
4	701	464
5	5,150	5,549

a. The numbers derived for both LPX-MED runs were based on running the model deterministically.

A final difference between the models that explains why they produce such different bed requirements is the dispersion factor. MPM adds on a 25-percent dispersion factor in calculating its bed requirements to account for the "fog of war." The calculation incorporating the dispersion factor is the MPM's last step when calculating bed requirements. LPX-MED has no analogous factor. Table 22 shows that applying the MPM dispersion factor to LPX-MED also reduces the differences in theater-level bed requirements significantly between the two models.

Finally, we find that when we apply the MPM rounding rules (of rounding to the nearest whole day) and the dispersion factor to LPX-MED, the in-theater bed requirement estimates from the two models move much closer. Table 23 shows that these two factors alone increase LPX-MED's in-theater bed requirements from 449 to 1,078, or more than 2 times. There remains only a small difference in the theater-level bed requirements: LPX-MED implies about an 8-percent lower bed requirement than MPM.

Table 23. Bed-day requirements assuming the same rounding and dispersion factors

Echelon	MPM	LPX-MED
3	418	251
4	751	827
5	1,779	5,716
Total	2,948	6,794

Using LPX-MED planning factors in MPM

The previous tables showed that MPM and LPX-MED lead to very different bed requirement values for the same combat scenario—that is, the same PAR and casualty stream. We provided several reasons why the in-theater values are lower in LPX-MED, and, once we impose rounding and dispersion, the numbers derived from LPX-MED move much closer to the MPM values. Should this outcome be expected with the new requirements model (i.e., MAT) or will it be difficult to take data from the 24 casualty clusters and use them appropriately in the calculator model? We can't really provide a definitive answer to these questions, but we can use the current scenario to show what might happen when the LPX-MED data are summarized and used in MPM.

Table 24 presents the planning factors required by MPM. We've repeated the values that we showed earlier for the MPM run itself in table 18, but now we present the values that were derived from the LPX-MED run. Taking the data from LPX-MED and modifying the values directly for use in MPM is a complex process. LPX-MED's treatment data for the 24 casualty clusters must be averaged to the many fewer casualty types required in MPM. This implies that we must average data that were already averaged from the individual treatment protocols of the DEPMEDS database. Also, whereas MPM assumes the same delay times for WIA and DNBI casualties, the data can be different in LPX-MED (indeed, as the table shows, they are different for echelon 4). Nonetheless, our goal is simply to illustrate what might happen when the new requirements model, MAT, relies on the same data to generate bed requirements.

Table 24. Planning factors for MPM based on LPX-MED treatment data

	From original MPM		From LPX-MED	
	WIA	DNBI	WIA	DNBI
Echelon 3				
Evacuation rate	0.92	0.67	1.00	1.00
ALOS for RTDs	5	5	1	1
Evacuation delay	3	3	1	1
Echelon 4				
Evacuation rate	0.83	0.38	1.00	0.94
ALOS for RTDs	9	9 or 6[a]	1	12
Evacuation delay	5	5	2	9

a. The ALOS is 9 for WIA and NBI casualties, but only 6 for disease.

Table 25 presents the bed requirement from the MPM model using the averaged data from LPX-MED. We can compare these values to the earlier values shown in table 19. The peak (in-theater) bed values are about 36 percent lower than what we found in the earlier MPM run. It's probably not surprising that the new values have moved closer to the LPX-MED values, much as the LPX-MED values moved closer to MPM values in the previous section when we imposed the MPM rounding and the dispersion assumptions on LPX-MED. But, why aren't they as close as those values? We believe much of the answer is due to simple averages being used to represent the much more complex data derived from LPX-MED. We conclude that it is important to use the same data in both the calculator and simulator models, but that it must be done carefully or very different implications may result.

Table 25. MPM bed requirements assuming LPX-MED treatment data

Echelon	Beds required
3	101
4	645
Total	746

Conclusions and recommendations

In this research memorandum, we have described the important planning factors each model requires and how the models use these factors to derive resource requirements. In addition to describing general differences that distinguish the three models, we used input values and assumptions from the same scenario to derive and compare the results from each model. This allowed us to focus on those factors and underlying relationships that are most important in determining requirements. In this final section, we summarize what we've found and suggest how we believe the new model—MAT—can incorporate some of these improvements.

In summary

Based on our analysis, we found that:

- How the models work and which assumptions drive the results the most were not well documented. Users of all three models must rely primarily on user's manuals that often hide, rather than illuminate, what's really going on.
  - As an example, the number of beds is important because it determines the requirement for other resources. Yet the manuals devote little discussion to how the models determine bed requirements. In the case of MEPES, there is almost no discussion.
- The two calculator models are very similar in most respects. That's not surprising, given that MEPES was developed as a follow-on to MPM. They do differ, however, in how they release those who return to duty at each echelon. In particular:
  - MEPES doesn't rely on input values for average lengths of stay for those who return to duty. It uses the parameters

describing the evacuation policy and delay as a means to distribute them over time.

— The distribution of those who return to duty from the medical facilities in MEPES will usually lead it to calculate a lower bed requirement than MPM. Its underlying method is not necessarily incorrect, just a different approach. Deciding which one to use will depend on which approach—a constant ALOS versus the distribution over time—is closer to reality.

- Comparisons of MPM and LPX-MED confirm that, for similar scenarios and casualties, we would expect MPM to require many more theater-level beds than LPX-MED. The reasons for this finding follow:

  — The LPX-MED treatment protocols and the way the model applies them will almost always cause most casualties to move to higher echelons.

  — The way each model rounds the time a patient spent in various queues and in a bed has a lot to do with differences observed in resource requirements. LPX-MED may be more precise in allocating time to the functions it does consider, but it's unclear if this extra precision better reflects reality because it does not model all functions.

  — The MPM dispersion factor, which represents uncertainty and other "uncontrollable" factors, also makes a large difference. LPX-MED doesn't use this factor in any of its bed requirement calculations.

Possible improvements

Given the foregoing conclusions, we offer several recommendations on how to improve the models and the process of determining requirements.

First, the concept of using calculator models, such as MPM, in conjunction with simulation models, such as LPX-MED, is a good one. Neither one alone is adequate for the task. Pure calculator models

can't deal adequately with uncertainty, other than by providing extra resources. Simulation models don't determine a requirement, but they can evaluate the resources put in place. Together, they could create a powerful tool, as described below:

- Even with the shortcomings in MPM/MEPES as calculator models, they will apparently serve as the basic framework for the future calculator model in MAT. As we show in appendix A, there are two somewhat different versions of MPM, with MAT being based on one of them. Therefore, it is important to ensure that, before MAT is "blessed," users understand and agree with its underlying assumptions.

- One caveat here is that MAT needs to incorporate ways of not only indicating shortfalls or bottlenecks, but also "efficiently" prescribing a way to recalculate a new requirement. Otherwise, an iterative process must be used, which can lead to inefficiencies.

- For MAT to address fully the uncertainties of war, we believe the model should incorporate a greater degree of uncertainty by increasing both the number of random variables and their default variance.

Second, as we indicated above, it's crucial that the underlying assumptions and equations within MAT be clearly stated, explained, and then followed in the computer code that will ultimately determine the numbers. Recent DOD standards have made a concerted effort to "validate" models before allowing their use by the services or even the Joint Staff. These standards may be too strong, but the idea is right: know what the model gives you before using it. Clearly, MPM, and probably the others we examined, would fail this kind of test.

We've shown that the underlying treatment data are important determinants in requirements. Yet, in many cases, other than referencing some other database, their validity remains unclear. Such major planning factors should be examined and validated. In LPX-MED, for example, the current treatment protocols it follows result from the aggregation of Defense Medical Standardization Board treatment

data. The appropriateness of this aggregation and how the model applies the resulting protocols have not been validated.

Related to the treatment data, it's also crucially important to clarify how military medicine operates today and how the databases and/or models will incorporate future changes. Do the LPX-MED (and presumably MAT) protocols, which imply minimal time in theater and evacuation after intensive care, reflect reality, or will treatment followed by return to duty in theater better reflect future procedures? This must be examined and answers made clear in MAT or any other model used to determine the future force structure.

Appendix A: Two alternative formulations of the MPM model

Introduction

This appendix provides additional details on how MPM calculates its bed requirements. For several reasons, we (as well as others) have found it difficult to reproduce the results from an MPM run. One important reason is that changes were made when the conceptual equations of the MPM model were translated to computer code and integrated into JOPES.[22] As often happens, changes may be made to models without careful documentation of the details of what was done. We feel it's important to understand the differences between the original equations and the "original" MPM (in JOPES) because the new version of MAT will be based, at least initially, on the original equations.

The scenario

We found it useful to use a JOPES MPM test scenario that specified the required input variables, such as the PAR, casualty, and evacuation rates, and provided the output results for requirements, such as beds. This allowed us to compare results to MEPES and LPX-MED, as well as to the results of using the original equations to represent MPM. The test scenario we used was one that the Joint Staff ran for analysts at OASD/PA&E, who also wanted to duplicate and verify the MPM calculations (although, from what we understand, they too experienced similar difficulties in doing so).

22. JOPES was intended to provide the planning community with automated tools for the development and appraisal of contingency plans. MPM was designed to be used by medical planners to quantify the impact of a proposed OPLAN on the medical system.

OPZ 1 results

We'll start with calculations for OPZ 1. In the present case, the basic scenario in the test run is fairly simple, but still captures the underlying method the model uses to calculate requirements. The assumed scenario begins at C-day (also denoted by C+0) and runs through C+120. The PAR is a constant 50,000 for the entire period from C+0 until C+119. Casualty rates for WIA, disease, and NBI are constant throughout, as are the evacuation rates, which were provided earlier in table 2. The killed-in-action rate is 0 and nobody dies of wounds or in hospital. (If the died-of-wounds rate was not 0, the equations we'll present shortly would have to be modified to take account of it.) The ALOS for all three types of casualties who eventually RTD at OPZ 1 is 5 days and there is a constant 3-day delay before evacuation to OPZ 2.

Calculating admissions, evacuations, and returns to duty

The information we've listed above is all that's needed to derive most important values at OPZ 1. Many, although not all, values reach *steady state* by C+10. MPM runs present output for C-day and the 10-day periods, such as from C+1 to C+10, C+11 to C+20, and so on. In some cases, the values represent the *peak* value; in other cases it might be the *average* value.

At OPZ 1, the formulas for such variables as admissions and evacuees are relatively straightforward and don't differ between the original equations and what was used in the MPM program to generate values. For example, once the PAR is known, the number of WIA casualties would be obtained by multiplying the PAR value by the wounded-in-action rate on that day. One slight complication for WIAs is that the rate used depends on the combat intensity level assumed for that day.

An example of an equation used to decribe an important variable is that for evacuations from one OPZONE to the next. In other words, the number of casualties at OPZ 1 or 2 who are evacuated to the next OPZONE (i.e., OPZ 2 or OPZ 3) can be represented by the same general formula, once the appropriate values for that OPZONE are substituted in the equation.

In general, the number of patients evacuated from OPZ x to OPZ y on day t is given by:

$$V_{(x,\,y),\,t} = \sum_{c} A_{x,\,c,\,t-d(x)} \times v_{(x,\,y),\,c,\,t} \quad , \tag{3}$$

where c represents the casualty type (i.e., WIA, disease, and NBI), $d(x)$ is the evacuation delay time at OPZ x, $A_{x,\,c,\,t\,-\,d(x)}$ represents the number of patients at OPZ x of casualty type c, who were admitted on day $t - d(x)$. The last term, $v_{(x,\,y),\,c,\,t}$, represents the evacuation rate from OPZ x to OPZ y on day t.

In a similar manner, we can determine the number of those who RTD at OPZ 1. The main complication here is the subscript on time because those who RTD on day t were actually admitted $h(1,c)$ days earlier, where this variable h represents the ALOS for casualty type c at OPZ 1. The equation for RTDs of type c on day t, which we represent by W, is given by :

$$W_{1,\,c,\,t} = A_{1,\,c,\,t-h(1,\,c)} \times (1 - v_{(1,\,2),\,c,\,t-h(1,\,c)+d(1)}) \ . \tag{4}$$

The number of RTDs at OPZ 1 is equal to the number of patients admitted on day $t - h(1,\ c)$ multiplied by 1 minus the evacuation rate at OPZ 1. The subscript on the evacuation rate looks complicated because the appropriate time period must take account of the ALOS as well as the evacuation delay time. For most runs of the model, including the one here, the evacuation rate doesn't change over time and the time subscript can be ignored. We include it for completeness. Also note that, had there been patients who died of wounds, a variable representing the percentage of such patients would have been subtracted from the second term as well.

Table 26 presents the calculated admissions, evacuations, and RTDs at OPZ 1 for the three casualty types. Given the constant PAR, combat intensity level, disease, and NBI rates, admissions are constant over

time as well.[23] The same holds true for evacuees and RTDs because they too rely on constant planning factors. For evacuations from OPZ 1 to OPZ 2, the assumed delay time is 3 days. Therefore, those admitted on day C+0 must wait 3 days before leaving on day C+3. The output results imply that these admittees spend 4 days in a bed at OPZ 1; the value includes the 3-day delay plus the day they move. RTDs, on the other hand, have a 5-day length of stay before leaving the bed. Those casualties admitted on day C+0 occupy a bed for 5 days—the day they are admitted plus the following 4 days. Note an important implication regarding the determination of beds: the time in a bed at an OPZONE is 1 day plus the evacuation delay for evacuees but is exactly the ALOS for those who return to duty.

Table 26. CNA calculated values at OPZ 1

	Admissions			Evacuees			RTDs		
Day	WIA	Disease	NBI	WIA	Disease	NBI	WIA	Disease	NBI
C+0	50	17	13						
C+1	50	17	13						
C+2	50	17	13						
C+3	50	17	13	46	11	9			
C+4	50	17	13	46	11	9			
C+5	50	17	13	46	11	9	4	6	4
C+6	50	17	13	46	11	9	4	6	4
C+7	50	17	13	46	11	9	4	6	4
C+8	50	17	13	46	11	9	4	6	4
C+9	50	17	13	46	11	9	4	6	4
C+10	50	17	13	46	11	9	4	6	4
Total (C+1 - C+10)	500	170	130	368	88	72	24	36	24
Values listed in MPM									
C+0	50	17	13						
C+1 - C+10	500	170	130	365	88	72		84[a]	

a. MPM only lists the total RTDs for the period, it doesn't break them out by casualty type.

23. It's usually fairly easy to duplicate admissions (although rounding is important to match exactly); the only complication arises when the PAR changes within a 10-day period. That doesn't happen in this case.

At this point, all total values shown in the last row match the output listing from the actual MPM run, with one minor exception. The listing shows that WIA evacuees total 365, which we believe is a simple error. There's no reason we can think of why there would be 3 fewer evacuees in the period.

Calculating bed requirements

The calculations for bed requirements at OPZ 1 will turn out to vary depending on which form of the requirement equation is used—that is, what we've been calling the original equations or those used by the JOPES MPM. In this section, we'll present both equations and indicate the differences that arise.

First, table 26 showed that the number of patients admitted on day C+0 is equal to 80 (the sum of 50 WIA, 17 disease, and 13 NBI casualties). In addition to the casualty-specific care requirement multipliers for determining the split between medical and surgical beds, one last piece of information is required for the actual calculation of beds. MPM assumes a "bed dispersion factor" that varies by OPZONE. The usual assumption is a 20-percent dispersion factor at OPZ 1, which translates to multiplying the beds by 1.25 in the final calculation.[24]

Table 27 presents the bed requirements for OPZ 1 for C-day and the peak requirements listed for the period between C+1 and C+10, which is also the steady state value in the run. For C-day, the calculation is straightforward and can be derived easily by multiplying the total admissions (i.e., 80) by 1.25 to obtain 100 beds. Even in this simple scenario, deriving later values for the bed requirement is somewhat more complicated and depends on which form of the equation one uses.

24. The equation for the bed dispersion multiplier is

$$\text{multiplier} = \frac{1}{1 - \text{bed dispersion factor}}$$
$$= \frac{1}{1 - 0.2}$$

Table 27. Peak bed requirements at OPZ 1

	Medical beds	Surgical beds	Total
C-day	36	64	100
C-1 to C-10	155	263	418

To derive values of the bed requirement, we'll start with the original equation, which we provide below:

$$R_{1,i,t} = \sum_{c} r_{c,i} \times \left[\sum_{k=0}^{h(1,c)} A_{1,c,t-k} - \sum_{k=d(1)}^{h(1,c)} V_{(1,2),c,t-k+d(1)} \right] . \quad (5)$$

The variable $r_{c,\,i}$ is a constant and describes the percentage of time that each casualty of type c spends in a bed of type i, where i = medical or surgical (the percentages were provided in table 7).

The equation seems relatively simple and sensible. It states that beds will depend on the accumulated admissions for each type of casualty through the ALOS less the number of patients who get evacuated out after waiting the $d(1)$ days of delay.

Sensible as the equation may seem, it does not lead to the bed requirements derived by the actual JOPES MPM run. Table 28 presents those numbers and, in the first line of the table, what we calculated using equation 5 (after accounting for the bed dispersion factor and rounding). The numbers based on the original equation are lower for both medical and surgical beds, with the total value lower by 65 beds, or about 16 percent.

Table 28. Peak bed requirements at OPZ 1 based on equations 5 and 6

	Medical beds	Surgical beds	Total
Original equation[a]	138	215	353
MPM run	155	263	418
Revised equation[b]	155	263	418

a. Based on equation 5.
b. Based on equation 6.

The reason for the difference is fairly subtle, but one that we indicated earlier: it depends on when patients vacate the beds when returning to duty or being evacuated to the next OPZONE.

Equation 5 implies that patients who RTD spend the ALOS plus one day in beds and patients who are evacuated spend the delay time in beds before they leave. The MPM model apparently was programmed to assume that an RTD spends only the ALOS in a bed, while an evacuee spends the delay time plus one day. Incorporating these assumptions requires only a simple modification to the equation:

$$R_{1,\,i,\,t} = \sum_{c} r_{c,\,i} \times \left[\sum_{k=0}^{h(1,\,c)-1} A_{1,\,c,\,t-k} - \sum_{k=d(1)+1}^{h(1,\,c)} V_{(1,\,2),\,c,\,t-k+d(1)} \right] \tag{6}$$

Using the same input values but now in equation 6 leads to the values found in the MPM run and also shown in table 28. Thus, a simple change in the assumed time before patients return to duty or are evacuated results in an 18-percent increase in bed requirements (from 353 to 418) for this scenario. This specific percentage will not hold for all scenarios, but our example points out the need to carefully consider even simple assumptions on which the model will rely.

OPZ 2 results

Calculating admissions, evacuations, and returns to duty

At OPZ 2, we've indicated that calculations become more complicated because of the two flows into medical facilities. There are evacuees who arrive from the first OPZONE, and there are casualties who originate directly at OPZ 2. Given the PAR at OPZ 2 of 25,000 and the corresponding casualty rates, it was not hard to derive admissions for all three casualty types.

As is often the case for an MPM run, the tables produced as part of the output run yielded only some of the required input values. For example, the OPZ 2 evacuation delay time was 5 days for all casualties and the theater-level evacuation rates were 83, 38, and 38 percent for WIA, disease, and NBI casualties, respectively. For some important

values—the ALOS for those patients who RTD at OPZ 2—the scenario relied on user-supplied values. Although it wasn't immediately obvious from the output listing, the ALOS for RTDs in the scenario was 9 days for WIA and NBI casualties and 6 days for disease.

With these values, we could then determine the number of evacuees from OPZ 2 to CONUS, and the *steady-state value* for RTDs. Unfortunately, it was less clear how MPM derived the value for the 10-day period from C+1 to C+10.[25] The difficulty we had deriving the 10-day value was one clue that the original equations for OPZ 2 were apparently modified for the JOPES MPM. In this and the next sections, we'll show what we believe are the differences in the equations for the number of RTDs for each type of casualty and how it ultimately affects the bed requirement. Although we never could match every value in the MPM run, the results using what we call the revised equations are much closer than the output values based on the original equations.

We'll begin with an equation that's the same for both versions, but we will point out where one of the variables in the equation must be interpreted the "right" way if the MPM values are to be derived. Earlier, we provided equation 3, which calculates how many of the casualties originating at either OPZ 1 or OPZ 2 will be evacuated to the next OPZONE (once the appropriate evacuation delay times and rates for that OPZONE are substituted in the equation). At OPZ 2, the total number of evacuees to CONUS also depends on those evacuees who originated at OPZ 1, face the OPZ 2 evacuation delay, and then get evacuated to OPZ 3 (i.e., CONUS).

The equation for patients who are evacuated from OPZ 1 to OPZ 2 and finally to OPZ 3 is given by:

$$V_{(1,2,3),t} = \sum_{c} V_{(1,2),c,t-d(2)-1} \times v_{(1,2,3),c,t} , \qquad (7)$$

25. We were very close for evacuees and RTDs, but found that MPM did not always round in a consistent manner. This is a minor problem, but does make it harder to duplicate results. In general, we found that we were closest to the actual MPM numbers when we rounded only at the end of a calculation.

where $v_{(1,2,3),c,t}$ is the evacuation rate from OPZ 2 to OPZ 3 on day t for patients of type c who were previously evacuated from 1 to 2 on day $t - d(2) - 1$. It is this evacuation rate that might be interpreted incorrectly. It is important to note that $v_{(1,2,3),t}$ is not the theater-level evacuation rate. That rate is given by the value for $v_{(2,3),t}$. The rate given by $v_{(1,2,3),t}$ must be multiplied by $v_{(1,2),t}$ to equal the theater-level rate $v_{(2,3),t}$.

The total number of evacuees from OPZ 2 to OPZ 3 would then be equal to:

$$V_{2,t} = V_{(2,3),t} + V_{(1,2,3),t}\ , \tag{8}$$

where the first term was provided earlier in equation 3 and the second from equation 7.

The equation representing those who RTD at OPZ 2 also includes two groups and is given by:

$$\begin{aligned} W_{2,t} = {} & \sum_c A_{2,c,t-h(2,c)} \times (1 - v_{(2,3),c,t-h(2,c)+d(2)}) \\ & + \sum_c V_{(1,2),c,t-h(2,c)-1} \times (1 - v_{(1,2,3),c,t-h(2,c)+d(2)}) \end{aligned} \tag{9}$$

The first term represents those casualties at OPZ 2 who return to duty at OPZ 2; that is, they are not evacuated to CONUS for additional care. The second term represents evacuees from OPZ 1 who eventually return to duty at OPZ 2. We believe the assumptions underlying when evacuees from OPZ1 return to duty at OPZ 2, and the number of RTDs at OPZ 2 that result, imply another important difference between the original equations and the MPM model.

Let's examine this term in more detail. We define $W_{(1,2),c,t}$, a variable that represents those casualties of type c who return to duty on day t at OPZ 2 having been evacuated from OPZ 1. Its value is given by the second term in equation 9 (after the summation sign). Note that the time subscript on the terms for $V_{(1,2)}$ and $v_{(1,2,3)}$ are relatively complicated because those who RTD on day t began as an evacuee $t - h(2, c) - 1$ days earlier, and the evacuation rate pertains to

the day that takes both the ALOS and the evacuation delay into account.

In the original equations, we believe the most likely interpretation of $h(2, c)$—the ALOS at OPZ 2 for casualty type c—is that the value is the same for casualties at OPZ 2 or evacuees from OPZ 1. In our test case, that would mean 9 days for WIA or NBI casualties, and 6 days for those with disease.

What the actual MPM model assumes for the ALOS at OPZ 2, however, depends on where the patient originated. If the patient is a new casualty, then $h(2, c)$ is 9 or 6 days. If, on the other hand, the patient originated at OPZ 1, then $h(2, c)$ must take into account the time spent in a bed at OPZ 1, or the evacuation delay plus 1 day. One could leave the equation for $W_{(1,2),c,t}$ alone in equation 9 but modify the interpretation of $h(2, c)$ to now be equal to $h(2, c) - (d(1) + 1)$, or to rewrite the term as follows:

$$W_{(1,2),c,t} = V_{(1,2),c,t-h(2,c)+d(1)} \times (1 - v_{(1,2,3),c,t-h(2,c)+d(2)+d(1)+1}) \quad . \tag{10}$$

In our simple case, with constant PAR and casualty rates over time, the changes that we've made in the equation won't affect the steady-state values, only the timing of the event. That would not be true in general, however. Furthermore, the next section shows that the change in interpretation of $h(2, c)$ affects the calculation for bed requirements as well.

Calculating OPZ 2 bed requirements

The bed dispersion factor is 15 percent at OPZ 2, which leads to a dispersion multiplier of 1.18. Once we include this factor, the care multipliers, and the values for those admitted on C-day (and round appropriately), the numbers of medical and surgical beds on the first day, for either the original equations or our modified version, is easily derived and shown in table 29.

Table 29. Peak bed requirements at OPZ 2

	Medical beds	Surgical beds	Total
C-day	18	31	49
C-1 to C-10	255	483	738

The table also provides the steady state value, which as we found earlier for OPZ 1, requires further explanation. Let's begin with equation 11, which is the expression based on the original equations, and represents the OPZ 2 requirement for bed type i on day t:

$$R_{2,i,t} = \sum_c r_{c,i} \times \left[\sum_{k=0}^{h(2,c)} A_{2,c,t-k} - \sum_{k=d(2)}^{h(2,c)} V_{(2,3),c,t-k+d(2)} + \sum_{k=1}^{h(2,c)} V_{(1,2),c,t-k-1} - \sum_{k=d(2)}^{h(2,c)} V_{(1,2,3),c,t-k+d(2)} \right] \quad (11)$$

The equation includes the two flows into the OPZONE: admissions from casualties at OPZ 2 and evacuees from OPZ 1. What must be subtracted from each of these are those patients who must be evacuated. Admittees at OPZ 2 must wait the specified delay, which in this case is 5 days, and then get evacuated to CONUS. Evacuees from OPZ 1 who don't RTD at OPZ 2 must also wait the specified period before being evacuated.

The problem is that this equation doesn't take account of other assumptions that we believe had been incorporated in the model. There are essentially two reasons why the bed requirements values will turn out to differ between a run based on the original equations and one based on what actually was used in the MPM. The first reason is the same as we observed for patients in OPZ 1. The time in beds for those who RTD is exactly that ALOS specified at OPZ 2, and not 1 day more, and the time in beds for evacuees is not just the assumed evacuation delay (5 days for all casualties), but the delay plus 1 day. We alluded to the second reason above: the ALOS for those who were evacuees from OPZ 1 includes the evacuation delay time (plus 1 day) experienced by the patients there.

Incorporating these changes in the equation for beds leads to equation 12:

$$R_{2,i,t} = \sum_c r_{c,i} \times \left[\sum_{k=0}^{h(2,c)-1} A_{2,c,t-k} - \sum_{k=d(2)+1}^{h(2,c)-1} V_{(2,3),c,t-k+d(2)} + \sum_{k=0}^{h(2,c)-1} V_{(1,2),c,t-k-1} - \sum_{k=d(2)+1}^{h(2,c)-1} V_{(1,2,3),c,t-k+d(2)} - \sum_{k=0}^{d(1)} W_{(1,2),c,t-k} \right] \quad (12)$$

Compared with equation 11, this equation has an additional term, one that must be subtracted from the others. This term represents the RTDs who originated at OPZ 1. The only reason the term must be included is because the ALOS for these patients at OPZ 2 includes the evacuation delay time at OPZ 1.

Before we turn to the actual values derived from equations 11 and 12, respectively, we should point out one implication that especially affects the bed calculations for those patients suffering from disease in the present case. In equation 11, the second and fourth terms pertain, respectively, to those admittees at OPZ 2 and evacuees from OPZ 1 who are, in turn, evacuated to OPZ 3. Note that because $h(2, c) > d(2)$, the term must be included in the calculation for beds. In equation 12, however, the summation takes place over the range from $d(2) + 1$ to $h(2, c) - 1$. But the former term, representing the lower bound, is equal to 6 and the latter term, representing the upper bound, equals 5. Therefore, the value for the entire term equals 0. Again, in a different case with different input parameters, this may not happen. But, it does happen here.

What are the calculated bed requirements in the two runs? Table 30 provides three sets of values: those based on equation 11, those observed in the actual MPM run, and those based on equation 12. The values based on the original equations are lower than either of the other values—58 lower than the MPM run and 71 lower than the values based on CNA's revised equation. The CNA revised equation is

much closer to the MPM run values, only off by 13 beds in total, but even that difference is unexplainable at present.

Table 30. Comparing OPZ 2 beds

Source of bed requirement calculation	Medical	Surgical	Total
Original equation[a]	241	439	680
MPM run	255	483	738
Revised equation[b]	244	507	751

a. Based on equation 11.
b. Based on equation 12.

We'll summarize this section with two final points. First, we'll state again that neither version matches the MPM run precisely. However, those interested in determining reasonable values for bed requirements have two alternatives to evaluate. They can then decide which set of assumptions seems more realistic and, therefore, would be more appropriate for calculating the bed requirement. Second, we reiterate that a simple change to some of the assumptions can have important effects on the bed requirement. The differences observed in the OPZ 1 and OPZ 2 bed requirement equations lead to differences in total theater-level beds of about 11 percent. The data inputs are the same; all that differs are seemingly innocuous assumptions concerning when patients leave their beds to return to duty or to be evacuated to a higher echelon of care. Nonetheless, significant differences in the bed requirement result from these simple changes.

OPZ 3 or CONUS results

The final set of results pertains to OPZ 3. Our discussion here will be brief, mainly for two reasons. First, theater-level requirements play a more important role in determining the future medical force structure than do the CONUS requirements. Second, although conceptually it should not be too difficult to duplicate the MPM values for CONUS bed requirements, in reality, we have found it difficult to do so. We believe the planning factors or other assumptions necessary to calculate the bed requirement aren't clearly stated or may even be

incorrect as shown in the planning factor tables provided in a typical MPM output (the tables are, at the least, misleading). We'll provide an example of this in a moment.

CONUS requirements depend on one flow in—evacuees from OPZ 2—and one flow out—patients sent to nonmilitary hospitals. Unlike beds in the first two OPZONEs, which in our calculations would reach steady-state early in the period (i.e., by day 10 or so), CONUS bed requirements don't reach steady-state values until after day C+30.

Table 31 presents the first two periods' listed requirements, but also presents the steady-state value, which occurs sometime after C+30. Not surprisingly, given the evacuation delays from either OPZONE, no beds are required at the start of the scenario. By day C+10, a total of 208 beds are required, and in steady-state almost 1,800 beds are required.

Table 31. Peak bed requirements at OPZ 3

	Medical beds	Surgical beds
C-day	0	0
C-1 to C-10	60	148
Steady-state	517	1,262

The calculation of CONUS beds depends on many of the same factors we've seen for OPZs 1 and 2. Once the evacuees arrive, they spend some time in bed before being returned to duty or spending some minimal time at a military facility before moving to the civilian sector. Given the similarities in the kinds of flows in and out of the two sectors, we believe that the same equations that represent OPZ 1 would, with the appropriate interpretation and substitution of the OPZ 3 planning factors, yield the values expected for OPZ 3.

Although the printed tables in the MPM test run suggest a 36-day, 30-day, and 30-day ALOS for WIA, disease, and NBI casualties, respectively, what MPM refers to as the CONUS retention policy/schedule dictates how fast casualties will be moved to the National Disaster Medical System (NDMS), which includes VA facilities. Often, a user

will assume different retention policies—some short, perhaps a few days, some much longer, 30 or 60 days—in order to bound the size of the requirement. There's nothing inherently wrong with trying to determine the bounds or sensitivity of a run to an assumption, such as this kind of delay. The problem was that we couldn't tell from the MPM output printout what assumptions were actually made for either the ALOS for RTDs or the retention policy for those who need more care.

These kinds of problems make it hard to reproduce the steady-state value, but other problems can arise based on what we said before was misleading information. One simple example concerns how long it takes for an evacuee to reach CONUS. The table showed a peak requirement of 208 beds required in CONUS during the 10-day period between C+1 and C+10. Given the flows we calculated for evacuees from OPZ 2 for each type of casualty for that period, and the assumption of a next-day arrival, we can derive the 208 beds on day C+10.

Yet, [1] states fairly clearly that an evacuee to OPZ 3 arrives after an entire day is spent traveling. Assuming the flows take place one day later and recalculating the bed requirement, we would derive a value of only 119 total beds, or a little more than half the requirement listed for the period. The difference of a day spent traveling makes little difference for calculating steady-state values. But it illustrates that what's sometimes described for the model and what's been calculated can be very different.

Appendix B: Calculating bed requirements in MEPES

Introduction

In this appendix, we present CNA's version of the mathematical equations that MEPES uses to calculate theater-level bed requirements. We derive the beds required at OPZs 1 and 2 to contrast the results based on a MEPES-like model with those based on either MPM or LPX-MED. We did not have access to the actual MEPES computer model; therefore, we derived the bed equations and developed a spreadsheet version of MEPES that allowed us to determine values for the bed requirement and other key variables.

Some differences between MEPES and MPM

Several differences between MEPES and MPM can affect the bed requirement calculations. The size of the individual effect will vary, but each requires at least a brief description.[26]

We've summarized five of the differences:

- Rounding rules in MEPES specified that anything 0.5 or less was rounded down to the nearest integer. For MPM, we rounded anything 0.5, or higher, up. We didn't follow the MEPES rule for a number ending in .5 because we wanted to concentrate on other factors that can affect the calculations.
- MEPES specifies a day for travel between OPZONEs. On this travel day, the patient isn't in a bed. He or she may require some sort of aeromedical evacuation asset, but not a bed. The

26. In some cases, our understanding of the differences was based on the MEPES Users' Manual and, in others, on discussions with SRA personnel.

MPM Users' Guide states that it allows a day's travel between OPZ 2 and OPZ 3, but we don't believe it ever counts a day during evacuation that the patient isn't in a bed. We imposed the MEPES assumption in our calculations but, in this simple scenario, it only affects when the model reaches steady state.

- Both users' manuals state similar rules concerning when the patient enters the bed (at 0001 hours) and when he or she leaves it for evacuation or to return to duty (at 2359 hours). We believe that MPM counts the evacuee as being in a bed for the delay time plus 1 day. Based on discussions with SRA, it seemed reasonable to assume this for MEPES as well.
- In the text, we described the distribution of when patients return to duty. Given our assumptions, the numbers of RTDs in steady state in both models are the same, but the way the MEPES calculations distribute them over time means they reach the steady state value much quicker. In MPM, they return whenever they reach their assumed ALOS. As we'll show, this bears implications for the required number of beds.
- The bed multipliers differ in the two models. MEPES calculates four types of beds, and MPM only two. For our comparison of the two models, we use the MPM multipliers and focus only on medical and surgical beds.

OPZ 1 results

We use the same scenario that we described in appendix A for MPM. This means there are three OPZONEs, constant casualty rates at both OPZ 1 and OPZ 2, and a 15-day theater evacuation policy. At OPZ 1, we continue to assume a 7-day policy.

We tried to focus on what we considered the major differences between the models. That meant assuming input values that were the same as MPM for casualty and evacuation rates between OPZONEs. Given the constant PAR, most important variable values would be equivalent.

Two variables that didn't match the MPM values were RTDs and beds. As we indicated in the text, MEPES counts two types of RTDs. At the

first OPZONE, there are only local RTDs. We define a variable δ_c, which is equal to the OPZ 1 evacuation delay less 1. Given the assumed 3-day delay time to OPZ 2, then $\delta_c = 3 - 1$, or 2, and half of the RTDs appear on the day following their admission and the remaining half 2 days later. Distributing the admissions in two days means that the model calculates a steady-state value for RTDs that's the same as MPM, but reaches it faster (i.e., closer to the start of the scenario).

What does this imply about the bed requirement? MPM assumes a 5-day ALOS for RTDs. The bed equation at OPZ 1 (given by equation 6 in appendix A) depends on 5 days of admissions less the first day's admittees who were evacuated after the assumed evacuation delay. The delay is 3 days, but the model's calculations assume that a total of 4 days was spent in an OPZ 1 bed. In MEPES, we'll also assume that patients spend 4 days in a bed before being evacuated. The bed requirement includes the admissions for the 4-day period, but must now subtract those who return to duty during the period.

Equation 13 provides the mathematical formulation for the bed type i requirement on day t using the same definition of variables as before, with the additional term for the distribution of RTDs. As we said above, $\delta_c = 2$, and the equation implies that, for $k = 0$, all of those who RTD from admissions on day t–3 will have been distributed and, therefore, will have vacated their beds by day t. For $k = 1$, only half of the RTDs from admissions on day t–2 will have done so. When $k = 2$, the distribution percentage is $(\delta - k)/\delta = 0$, implying that no one who was admitted on day t–1 will have returned to duty by day t. Therefore, there's no need to subtract them from the bed requirement.

$$R_{1,i,t} = \sum_c r_{c,i} \times \left[\sum_{k=0}^{d(1)} A_{1,c,t-k} - \sum_{k=0}^{\delta_c} \frac{\delta_c - k}{\delta c} \times (1 - v_{(1,2),c,t+k}) \times A_{1,c,t+k-d(1)} \right] \tag{13}$$

We assume the same bed multipliers (i.e., the $r_{c,i}$'s) and dispersion factor (at OPZ 1, it was 1.25) as in MPM. Incorporating these factors

into equation 13, we obtain a bed requirement at OPZ 1 of 133 medical and 241 surgical beds. The total number of beds—374 beds in MEPES versus 418 beds in MPM—represents a decrease of about 11 percent.

OPZ 2 results

Because of the two flows into OPZ 2 (new casualties at OPZ 2 and evacuees at OPZ 1), the bed equations include terms representing both local and transfer RTDs. In MPM, the scenario assumed that there were differences between the ALOS at OPZ 2 for the three types of casualties. WIA and NBI casualties who returned to duty at OPZ 2 were assumed to have an ALOS of 9 days, but disease casualties were assumed to stay only 6 days in a bed.

MEPES makes no distinction among the different kinds of casualties; they all face the same distribution percentage, which is based on δ_c. Given the assumed 5-day delay at OPZ 2, $\delta_c = 5 - 1$, which implies that 25 percent of the patients who aren't evacuated would RTD on each of the four days following the day of their admission. This implies that a local RTD would average 3.5 days in a bed, versus the 9 or 6 days, depending on the type of casualty, in MPM.

Because of the transfer RTDs, equation 14 becomes a bit more complicated. We define a second term δ_e, which is equal to the evacuation policy in the OPZONE less the accumulated evacuation delays from earlier OPZONEs less 1 (this formulation was discussed in the main text). Given the assumptions of a 15-day evacuation period and a 3-day delay at OPZ 1, the distribution period would be over 11 days (distribution = $1/[15 - 3] - 1$), or about 9 percent each day. Given the PAR and casualty rates assumed, there are fewer than 11 RTDs for each casualty type. We assumed a distribution of one each day beginning the day after the evacuee arrives (in other words, when there are less than whole numbers of RTDs, it seems reasonable to always round the number to be distributed up to the nearest whole number). Note that in the term for transfer RTDs in equation 14, the upper limit for the summation is $d(2)$, not δ_e because $d(2) < \delta_e$ and when there are large numbers of transfer RTDs, some must be distributed after day t.

Equation 14 represents the number of beds required at OPZ 2, with both evacuees from OPZ 1 and casualties at OPZ 2 being distributed:

$$R_{2,i,t} = \sum_c r_{c,i} \times \left[\sum_{k=0}^{d(2)} (V_{(1,2),c,t-k-1} + A_{2,c,t-k}) \right.$$
$$+ \sum_{k=0}^{d(2)} \frac{d(2)-k}{\delta_e} \times (1 - v_{(2,3),c,t+k}) \times V_{(1,2),c,t-k-1-d(2)}$$
$$\left. + \sum_{k=0}^{\delta_c} \frac{\delta_c - k}{\delta_c} \times (1 - v_{(2,3),c,t+k}) \times A_{2,c,t-k} \right] \quad (14)$$

The first two terms represent the beds required for each of the two flows into the sector—the evacuees from OPZ 1 and the new casualties at OPZ 2. The last two terms represent the beds vacated by the transfer and local RTDs.

Because of the way MEPES distributes the RTDs, the steady-state bed requirement value is not reached until after the corresponding day for MPM. The MEPES steady-state medical and surgical bed requirements are 196 and 430, respectively, which when summed, represent a decrease of almost 10 percent from the steady-state MPM value (the main text provides additional discussion of the two models' implications for the bed requirement).

OPZ 3 or CONUS results

As we observed for MPM, the bed requirement calculation for OPZ 3 in MEPES should be relatively straightforward. There are no casualties and the only flow in represents those evacuees from a forward OPZONE—in this case, OPZ 2. The number of beds required would depend on how long they remain in a military bed either before they return to duty or when they move to the civilian sector. We face the same problem for calculating bed requirements that we had for MPM—namely, we're not sure what percentages of the evacuees return to duty or move to the civilian sector.

However, we can show how MEPES would distribute RTDs conceptually. Assuming a 60/10 retention policy, and because all of the evacuees who return to duty at CONUS are transfer RTDs, the model distributes them using the following relationship:

$$\begin{aligned}\text{Distribution percentage} &= \frac{1}{[60-8]-1} \\ &= \frac{1}{51}\end{aligned} \tag{15}$$

In other words, those who entered CONUS facilities on day t would start returning to duty on day t+1 and, assuming the number of RTDs is large enough, continue through t+52.

The only other group remaining includes those waiting to move to civilian facilities. They wait 10 days and then leave the DOD facility. The bed requirement would have to take account of the flow of evacuees into OPZ 3 less these two flows out.

Appendix C: MAT patient treatment data

The following table is a listing of LPX-MED's patient treatment file, which the model refers to as typeptnt.med. These data are derived from the DMSB Deployable Medical Systems (DEPMEDS) Time, Task, Treater file, which contains treatment requirements for individual patient conditions. LPX-MED aggregates the DEPMEDS data into treatment profiles for 24 patient conditions. We find that these 24 protocols often describe treatment that appears unlikely any individual would actually follow. For example, some of the protocols trigger evacuation to the next echelon of care for minimal (less than a day) treatment times.

Table 32 gives the patient treatment times by echelon for each of the 24 patient conditions in LPX-MED. The wia_factor and dnbi_factor associated with each protocol give the percentage of WIA and DNBI who will have that patient condition.

Table 32. MAT patient treatment data

Multiple injury wounds (WIA)

wia_factor	0.072569
dnbi_factor	0

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	2	2	2	2	2
OPERATING_ROOM	3.1	3.7	4.3	4.9	5.4
INTENSIVE_CARE_UNIT	30.3	36.8	43.3	49.8	56.3
INTERMED_CARE_WARD	13.2	17.4	21.6	24	24
Echelon IV					
ER/TRIAGE/XRAY/LAB	1.4	1.7	1.9	2	2
OPERATING_ROOM	0.9	1.2	1.5	1.8	2
INTENSIVE_CARE_UNIT	0	0	11.3	25.5	39.7
INTERMED_CARE_WARD	49.6	66.4	83.1	99.8	116.5
MINIMAL_CARE_WARD	0	0	75.8	203.1	330.4
Echelon V					
ER/TRIAGE/XRAY/LAB	0.3	0.4	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	15	45.4	75.8	106.2	136.6
INTERMED_CARE_WARD	0	113.2	376.8	640.5	904.1
MINIMAL_CARE_WARD	357.7	962.3	1566.8	2171.3	2775.8

Table 32. MAT patient treatment data (continued)

Head wounds

wia_factor	0.016767
dnbi_factor	0.002117

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0	0.1	0.3	0.4	0.5
INTENSIVE_CARE_UNIT	0	0	10.5	21.1	31.7
INTERMED_CARE_WARD	0	4.4	30	55.5	81
MINIMAL_CARE_WARD	0	28.7	99.5	170.3	241.2
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0	0.3	0.6	0.9
OPERATING_ROOM	0	0	0.1	0.3	0.4
INTERMED_CARE_WARD	0	0	7.7	15.9	24.1
MINIMAL_CARE_WARD	0	0	30.7	68	105.2
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0	0.1	0.2	0.4
OPERATING_ROOM	0	0	0.1	0.2	0.4
INTERMED_CARE_WARD	0	0	23	81	139
MINIMAL_CARE_WARD	0	0	42.1	148.5	254.9

Table 32. MAT patient treatment data (continued)

Upper extremeties

wia_factor	0.130133
dnbi_factor	0

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	1.6	1.8	1.9	2	2
OPERATING_ROOM	1.5	1.8	2.2	2.6	3
INTENSIVE_CARE_UNIT	2.6	8.5	14.4	20.3	24
INTERMED_CARE_WARD	18.7	23.9	29.1	34.3	39.5
MINIMAL_CARE_WARD	0	0	9.1	49.6	90
Echelon IV					
ER/TRIAGE/XRAY/LAB	1.2	1.5	1.8	2	2
OPERATING_ROOM	0.8	1.1	1.3	1.6	1.9
INTENSIVE_CARE_UNIT	0	0	1.3	4	6.7
INTERMED_CARE_WARD	9.6	28.2	46.9	65.5	84.2
MINIMAL_CARE_WARD	0	0	180.4	380.8	581.2
Echelon V					
ER/TRIAGE/XRAY/LAB	0.2	0.3	0.4	0.5	0.5
INTENSIVE_CARE_UNIT	7.3	18.2	29.2	40.2	51.2
INTERMED_CARE_WARD	70.1	130.5	191	251.5	312
MINIMAL_CARE_WARD	576.9	883.3	1189.7	1496.1	1802.5

Table 32. MAT patient treatment data (continued)

Chest/abdomen (WIA)

wia_factor	0.095268
dnbi_factor	0

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	1.6	1.8	1.9	2	2
OPERATING_ROOM	1.2	1.8	2.3	2.9	3.5
INTENSIVE_CARE_UNIT	10.9	26.2	41.4	56.6	71.8
INTERMED_CARE_WARD	5.2	21.1	37.1	53.1	69.1
MINIMAL_CARE_WARD	0	0	65.3	154.1	242.9
Echelon IV					
ER/TRIAGE/XRAY/LAB	0.2	0.6	1	1.5	1.9
OPERATING_ROOM	0	0.2	0.5	0.8	1.2
INTENSIVE_CARE_UNIT	0	0	0.1	2.4	4.7
INTERMED_CARE_WARD	0	75.3	161.3	247.3	333.3
MINIMAL_CARE_WARD	0	81.8	255.5	429.1	602.8
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0.1	0.2	0.4	0.5
INTENSIVE_CARE_UNIT	0	0	42.3	91.6	140.8
INTERMED_CARE_WARD	0	38.9	114	189	264.1
MINIMAL_CARE_WARD	0	261.7	695	1128.4	1561.8

Table 32. MAT patient treatment data (continued)

Lower extremeties (WIA)

wia_factor	0.227272
dnbi_factor	0

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	1.8	1.9	2	2	2
OPERATING_ROOM	1.9	2.3	2.8	3.2	3.7
INTENSIVE_CARE_UNIT	8.6	13.7	18.8	23.9	29
INTERMED_CARE_WARD	23.9	30	36.1	42.1	48
MINIMAL_CARE_WARD	0	0	1	14.5	28.1
Echelon IV					
ER/TRIAGE/XRAY/LAB	1.2	1.5	1.7	2	2
OPERATING_ROOM	0.7	1	1.3	1.6	1.9
INTENSIVE_CARE_UNIT	0	0	0.3	1.7	3
INTERMED_CARE_WARD	33	39.3	45.6	51.9	58.2
MINIMAL_CARE_WARD	0	0	1.6	17.9	34.1
Echelon V					
ER/TRIAGE/XRAY/LAB	0.5	0.5	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	14.6	25.9	37.1	48.3	59.6
INTERMED_CARE_WARD	143.9	266.5	389.1	511.7	634.3
MINIMAL_CARE_WARD	782.2	1324.3	1866.3	2408.4	2950.4

Table 32. MAT patient treatment data (continued)

Superficial/soft tissue wounds					
wia_factor	0.198763				
dnbi_factor	0.007983				
Patient treatment times (in hours) by acuity level (1-5)					
Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.9	1.3	1.6	1.9	2
OPERATING_ROOM	0.5	0.9	1.4	1.8	2.3
INTERMED_CARE_WARD	15.9	49.6	83.4	117.1	150.8
MINIMAL_CARE_WARD	248	295	342	388.9	435.9
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0	0	0.1	0.1
OPERATING_ROOM	0	0	0	0	0.1
INTERMED_CARE_WARD	0	0	1.1	4.1	7.1
MINIMAL_CARE_WARD	0	0	9.6	36.9	64.2

Table 32. MAT patient treatment data (continued)

Burns

wia_factor	0.050051
dnbi_factor	0.003823

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.2	0.6	1	1.4	1.8
OPERATING_ROOM	0	0.1	0.3	0.5	0.7
INTENSIVE_CARE_UNIT	2.6	13.4	24.2	35	45.8
INTERMED_CARE_WARD	0.6	29.7	58.7	87.8	116.9
MINIMAL_CARE_WARD	0	56.4	154.1	251.7	349.4
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0.2	0.4	0.6	0.8
OPERATING_ROOM	0	0	0	0.1	0.2
INTENSIVE_CARE_UNIT	0	0	5.3	10.8	16.3
INTERMED_CARE_WARD	0	10.5	43.2	75.9	108.5
MINIMAL_CARE_WARD	0	0	80.6	175	269.4
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0.1	0.3	0.4	0.5
INTENSIVE_CARE_UNIT	0	11.8	37.3	62.9	88.5
INTERMED_CARE_WARD	0	112.2	263.1	414	564.9
MINIMAL_CARE_WARD	0	420.6	943.7	1466.7	1989.8

Table 32. MAT patient treatment data (continued)

Miscellaneous WIA

wia_factor	0.02002
dnbi_factor	0

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0	0	0	1.5	1.5
OPERATING_ROOM	0	0	0	0	0
INTENSIVE_CARE_UNIT	0	0	0	48	72
INTERMED_CARE_WARD	0	0	0	120.8	120
MINIMAL_CARE_WARD	0	0	0	240	360
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0	0	0	1.5
OPERATING_ROOM	0	0	0	0	0
INTENSIVE_CARE_UNIT	0	0	0	0	0
INTERMED_CARE_WARD	0	0	0	0	168
MINIMAL_CARE_WARD	0	0	0	0	720

Table 32. MAT patient treatment data (continued)

1st priority surgery

wia_factor	0.029445
dnbi_factor	0.000131

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
MASH_ER	2	2	2	2	2
OPERATING_ROOM	1.2	2.5	3.9	5.3	6.5
INTENSIVE_CARE_UNIT	24	24	56.8	89.6	96
INTERMED_CARE_WARD	5.6	13.9	22.3	30.6	39
Echelon IV					
ER/TRIAGE/XRAY/LAB	0.5	0.6	1.5	2	2
OPERATING_ROOM	0	0	0.8	1.8	2.5
INTENSIVE_CARE_UNIT	0	0	12.5	38	63.5
INTERMED_CARE_WARD	0	25.6	75.2	124.8	174.5
MINIMAL_CARE_WARD	0	0	32.4	332.8	633.3
Echelon V					
ER/TRIAGE/XRAY/LAB	0.1	0.3	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	0	7.2	106.8	206.5	240
INTERMED_CARE_WARD	0	0	395.6	839.3	1282.9
MINIMAL_CARE_WARD	0	456	1640.3	2824.6	3768

Table 32. MAT patient treatment data (continued)

Battle fatigue

wia_factor	0
dnbi_factor	0.095737

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0	0.1	0.2	0.3	0.4
INTERMED_CARE_WARD	0	6.3	15.5	24.7	33.9
MINIMAL_CARE_WARD	0	15.5	43.8	72	100.3
Echelon IV					
CLINICS	0	0.1	0.1	0.2	0.3
INTERMED_CARE_WARD	0	3.1	8.5	13.9	19.3
MINIMAL_CARE_WARD	0	52.5	118.6	184.7	250.8
Echelon V					
CLINICS	0	0	0.1	0.1	0.1
INTERMED_CARE_WARD	0	3.9	14.1	24.4	34.6
MINIMAL_CARE_WARD	0	42.6	155.3	267.9	380.6

Multiple injury wounds (NBI)

wia_factor	0
dnbi_factor	0

No patients with this condition

Table 32. MAT patient treatment data (continued)

Head/neck center

wia_factor	0.139701
dnbi_factor	0.002378

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
HEAD/NECK_ER	1.5	1.7	1.9	2	2
OPERATING_ROOM	1.3	2.1	3	3.8	4.6
INTENSIVE_CARE_UNIT	14	30.1	46.2	62.3	78.4
INTERMED_CARE_WARD	0	0	35.6	73.6	111.6
MINIMAL_CARE_WARD	0	0	33	98	163
Echelon IV					
HEAD/NECK_ER	0.9	1.3	1.7	2	2
OPERATING_ROOM	0.5	1	1.5	2	2.5
INTENSIVE_CARE_UNIT	0	9.5	23.2	36.8	50.4
INTERMED_CARE_WARD	22.7	56.8	90.9	125	159.2
MINIMAL_CARE_WARD	0	0	82.5	189.8	297.1
Echelon V					
HEAD/NECK_ER	0.2	0.3	0.4	0.5	0.5
INTENSIVE_CARE_UNIT	0	24.1	51.2	78.3	105.4
INTERMED_CARE_WARD	0	202.9	972.9	1743	2513
MINIMAL_CARE_WARD	143.8	1125.2	2106.5	3087.8	4069.1

Table 32. MAT patient treatment data (continued)

Upper extremeties (NBI)

wia_factor	0				
dnbi_factor	0.003952				

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.3	0.7	1	1.4	1.8
OPERATING_ROOM	0	0.2	0.7	1.2	1.7
INTENSIVE_CARE_UNIT	0	0	2	5.2	8.4
INTERMED_CARE_WARD	17	23.8	30.7	37.6	44.4
MINIMAL_CARE_WARD	0	9.5	114.7	220	325.3
Echelon IV					
ER/TRIAGE/XRAY/LAB	0.2	0.6	1.1	1.5	2
OPERATING_ROOM	0	0.4	0.8	1.3	1.8
INTENSIVE_CARE_UNIT	0	0	0.1	0.8	1.6
INTERMED_CARE_WARD	0	22	46	69.9	93.9
MINIMAL_CARE_WARD	0	222.2	477.1	732	986.9
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0	0.1	0.2	0.3
OPERATING_ROOM	0	0	0	0	0
INTENSIVE_CARE_UNIT	0	0.1	11	21.9	32.9
INTERMED_CARE_WARD	0	8	68.1	128.2	188.3
MINIMAL_CARE_WARD	0	9.3	660.8	1312.4	1963.9

Table 32. MAT patient treatment data (continued)

Chest/abdomen (NBI)

wia_factor	0
dnbi_factor	0.001693

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.8	1.1	1.5	1.9	2
OPERATING_ROOM	0	0.7	1.4	2	2.7
INTENSIVE_CARE_UNIT	1.5	12.5	23.6	34.6	45.6
INTERMED_CARE_WARD	0	11.4	32.4	53.4	74.5
MINIMAL_CARE_WARD	0	16.5	92.4	168.3	244.2
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0.2	0.5	0.9	1.2
OPERATING_ROOM	0	0	0.2	0.4	0.6
INTENSIVE_CARE_UNIT	0	0	0.3	6.6	13
INTERMED_CARE_WARD	0	68.4	144.2	219.9	295.6
MINIMAL_CARE_WARD	25.3	226.9	428.5	630.1	831.7
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0	0.1	0.1	0.2
INTENSIVE_CARE_UNIT	0	0	6.8	33.1	59.4
INTERMED_CARE_WARD	0	0	30	97.6	165.3
MINIMAL_CARE_WARD	0	0	126.3	355.6	585

Table 32. MAT patient treatment data (continued)

Lower extremeties (NBI)

wia_factor	0
dnbi_factor	0.006514

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.8	1.1	1.5	1.8	2
OPERATING_ROOM	0.1	0.6	1.1	1.7	2.2
INTENSIVE_CARE_UNIT	0	5.5	11.7	17.8	24
INTERMED_CARE_WARD	11.8	18.2	24.6	31	37.5
MINIMAL_CARE_WARD	0	0	85.3	200.4	315.4
Echelon IV					
ER/TRIAGE/XRAY/LAB	0.4	0.8	1.2	1.6	2
OPERATING_ROOM	0	0.4	0.9	1.4	1.9
INTENSIVE_CARE_UNIT	0	0.4	5.4	10.4	15.4
INTERMED_CARE_WARD	12.1	24.7	37.2	49.8	62.4
MINIMAL_CARE_WARD	0	0	7.8	45.1	82.3
Echelon V					
ER/TRIAGE/XRAY/LAB	0.3	0.3	0.4	0.5	0.5
INTENSIVE_CARE_UNIT	0	4.2	15.6	27.1	38.6
INTERMED_CARE_WARD	0	103.8	216.7	329.7	442.7
MINIMAL_CARE_WARD	616.4	1116.9	1617.3	2117.8	2618.2

Table 32. MAT patient treatment data (continued)

Sprains

wia_factor	0.01001
dnbi_factor	0.015593

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.2	0.3	0.5	0.5	0.5
INTERMED_CARE_WARD	0	6.9	15.4	24	32.5
MINIMAL_CARE_WARD	70.7	171.4	272	372.7	456
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0.1	0.3	0.5	0.7
OPERATING_ROOM	0	0	0.1	0.3	0.4
INTERMED_CARE_WARD	0	0.2	5.3	10.3	15.3
MINIMAL_CARE_WARD	0	50.2	170.7	291.1	411.6
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0	0	0	0.1
INTENSIVE_CARE_UNIT	0	0	0.9	2.2	3.6
INTERMED_CARE_WARD	0	0	11.4	29	46.6
MINIMAL_CARE_WARD	0	0	39.4	100.4	161.4

Table 32. MAT patient treatment data (continued)

Miscellaneous (NBI)

wia_factor	0
dnbi_factor	0.004422

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.1	1	1.9	2	2
OPERATING_ROOM	0	0.4	0.7	1	1
INTENSIVE_CARE_UNIT	0	11.2	22.5	33.8	45.1
INTERMED_CARE_WARD	0.4	25.8	51.2	76.6	96
MINIMAL_CARE_WARD	0	39.4	78.9	118.4	158
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0.5	0.9	1.4	1.9
OPERATING_ROOM	0	0.2	0.5	0.7	0.9
INTERMED_CARE_WARD	0	22.3	44.9	67.5	90.1
MINIMAL_CARE_WARD	0	223.3	449.2	675.2	901.1

Table 32. MAT patient treatment data (continued)

Environmental injuries					
wia_factor	0				
dnbi_factor	0.008685				
Patient treatment times (in hours) by acuity level (1-5)					
Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0.1	0.3	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	0	7.7	20.6	33.4	46.2
INTERMED_CARE_WARD	18.3	66.8	115.3	163.8	168
MINIMAL_CARE_WARD	22.9	158.5	294	429.6	528
Echelon IV					
ER/TRIAGE/XRAY/LAB	0	0	0.1	0.2	0.3
INTERMED_CARE_WARD	0	16.8	75.6	134.3	193
MINIMAL_CARE_WARD	0	14.9	76.4	137.8	199.3
Echelon V					
ER/TRIAGE/XRAY/LAB	0	0	0	0.1	0.1
INTERMED_CARE_WARD	0	0	29.9	60.8	91.8
MINIMAL_CARE_WARD	0	0	152	313.4	474.8

Table 32. MAT patient treatment data (continued)

Respiratory diseases

wia_factor	0				
dnbi_factor	0.297609				
Patient treatment times (in hours) by acuity level (1-5)					
Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0.4	0.5	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	0	8.4	18.9	29.5	40
INTERMED_CARE_WARD	23.1	36.2	49.3	62.4	75.5
MINIMAL_CARE_WARD	36.2	89.6	143.1	196.5	249.9
Echelon IV					
INTERMED_CARE_WARD	0	0	0.4	1	1.6
MINIMAL_CARE_WARD	0	0	0.4	1	1.6
Echelon V					
MINIMAL_CARE_WARD	0	0	24.5	59.9	95.2

Table 32. MAT patient treatment data (continued)

Gastrointestinal diseases					
wia_factor	0				
dnbi_factor	0.194481				
Patient treatment times (in hours) by acuity level (1-5)					
Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0.4	0.4	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	0	0	0.2	0.8	1.4
INTERMED_CARE_WARD	20.7	31.8	42.9	54	65
MINIMAL_CARE_WARD	81.3	101.2	121.1	140.9	160.8
Echelon IV					
INTENSIVE_CARE_UNIT	0	0	0.1	0.7	1.3
INTERMED_CARE_WARD	0	0	1.3	4	6.8
MINIMAL_CARE_WARD	0	0	0.4	3.1	5.7
Echelon V					
INTENSIVE_CARE_UNIT	0	0	0.1	0.8	1.5
INTERMED_CARE_WARD	0	0	1.9	6.4	10.9
MINIMAL_CARE_WARD	0	0	10.9	33.5	56.2

Table 32. MAT patient treatment data (continued)

Infectious/parasitic diseases

wia_factor	0
dnbi_factor	0.071374

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0.5	0.5	0.5	0.5	0.5
INTENSIVE_CARE_UNIT	0	7.7	20.3	32.8	45.4
INTERMED_CARE_WARD	29.8	43.1	56.3	69.6	82.9
MINIMAL_CARE_WARD	78.5	125.9	173.4	220.9	268.3
Echelon IV					
CLINICS	0	0	0.1	0.2	0.3
INTERMED_CARE_WARD	0	4.2	13.8	23.5	33.1
MINIMAL_CARE_WARD	0	42.6	123.4	204.3	285.1
Echelon V					
INTERMED_CARE_WARD	0	0	17.9	65.7	113.4

Sexually transmitted diseases

wia_factor	0
dnbi_factor	0.055257

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0	0.3	0.5	0.5	0.5
INTERMED_CARE_WARD	5.9	69.8	133.7	168	168
MINIMAL_CARE_WARD	6.9	77.2	147.4	168	168

Table 32. MAT patient treatment data (continued)

Miscellaneous

wia_factor	0
dnbi_factor	0.227677

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
CLINICS	1.5	1.5	1.5	1.5	1.5
Echelon III					
CLINICS	0	0.4	0.8	1.1	1.5
OPERATING_ROOM	0	0	0.2	0.3	0.5
INTENSIVE_CARE_UNIT	0	1.6	4.4	7.3	10.1
INTERMED_CARE_WARD	4.6	36.7	68.9	101	133.2
MINIMAL_CARE_WARD	1.9	58.3	114.7	171.1	227.4
Echelon IV					
CLINICS	0	0	0.1	0.2	0.3
OPERATING_ROOM	0	0	0.1	0.1	0.2
INTENSIVE_CARE_UNIT	0	0	0.1	0.4	0.8
INTERMED_CARE_WARD	0	3.7	14.2	24.7	35.2
MINIMAL_CARE_WARD	0	10.7	52.3	93.9	135.4
Echelon V					
CLINICS	0	0	0	0	0.1
INTENSIVE_CARE_UNIT	0	0	0	0.2	0.5
INTERMED_CARE_WARD	0	0	26	54.5	83.1
MINIMAL_CARE_WARD	0	1	70.5	139.9	209.3

Table 32. MAT patient treatment data (continued)

Spine

wia_factor	0.01001
dnbi_factor	0.000569

Patient treatment times (in hours) by acuity level (1-5)

Echelon II					
ER/TRIAGE/XRAY/LAB	1.5	1.5	1.5	1.5	1.5
Echelon III					
ER/TRIAGE/XRAY/LAB	0.6	0.9	1.3	1.7	2
OPERATING_ROOM	0.1	1.2	2.3	3.4	4.5
INTENSIVE_CARE_UNIT	9.3	19.4	29.5	39.6	48
INTERMED_CARE_WARD	0	2.5	8.2	13.9	19.6
Echelon IV					
ER/TRIAGE/XRAY/LAB	0.8	1.2	1.5	1.9	2
OPERATING_ROOM	0.2	0.7	1.1	1.6	2.1
INTENSIVE_CARE_UNIT	3.7	13.4	23.1	32.7	42.4
INTERMED_CARE_WARD	0	48.1	139.8	231.5	323.1
MINIMAL_CARE_WARD	0	24.8	194.7	364.5	534.3
Echelon V					
ER/TRIAGE/XRAY/LAB	0.2	0.3	0.4	0.5	0.5
INTENSIVE_CARE_UNIT	0	0	8.5	17.3	26.1
INTERMED_CARE_WARD	762.9	3667.5	6572.2	9476.9	9999.9
MINIMAL_CARE_WARD	0	0	338.2	692.9	1047.6

References

[1] *Joint Operation Planning and Execution System (JOPES), Medical Planning Module (MPM), Users' Manual,* 10 Oct 1992 (Defense Systems Support Organization, Computer System Manual CSM UM 231-92)

[2] *Medical Planning and Execution System (MEPES), MEPES Core Users' Manual,* Nov 1994 (Systems Research and Applications Corporation, TR-94-1248030-0078)

[3] Joint Chiefs of Staff/J4/Medical Readiness Division, *External Logistics Processor—Medical Module (LPXMED—User's Guide, Version 4.1* (and LPXMED 4.1 software), Jun 1995 (prepared by Booz Allen & Hamiliton Inc.)

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